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Nitrate Removal for Small Public Water Systems

SMC Martin, Inc., Valley Forge, PA

Prepared for

Environmental Protection Agency, Washington, DC

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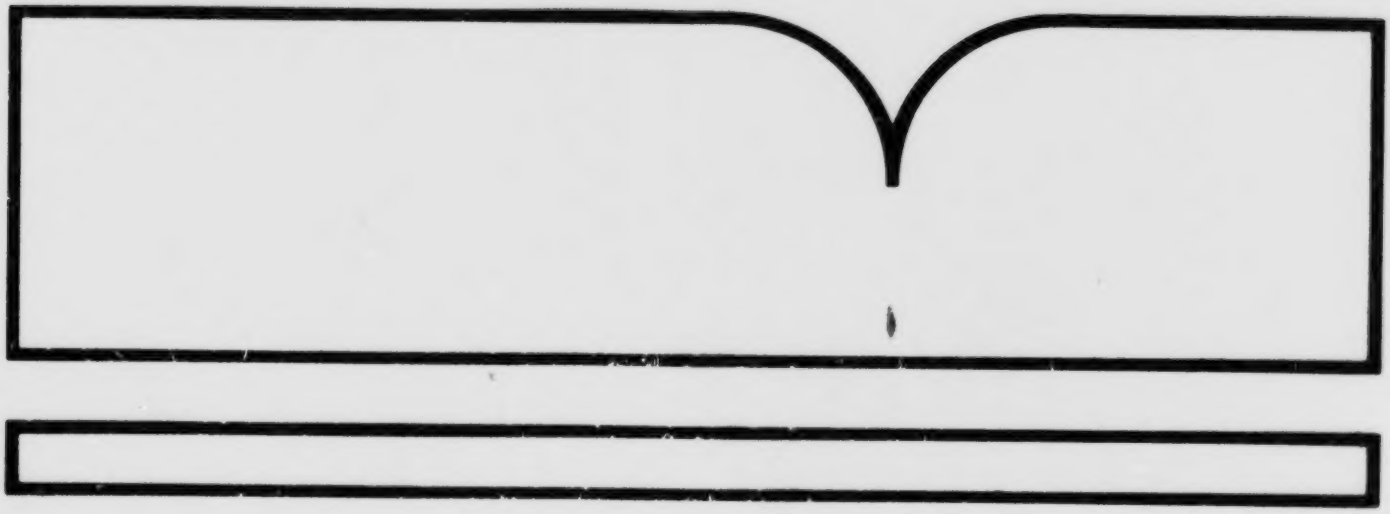

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This Handbook for Nitrate Removal has been prepared to aid water utility owners, engineers, operators, and municipal managers in understanding and dealing with excessive nitrate levels in their water supply. It is intended to be used for defining the problem, developing or evaluating proposed solutions, and explaining to water consumers why nitrates are controlled and what the approximate costs of control will be. This handbook is designed as a technical guide to nitrate removal for those smaller size systems that have decided that nitrate control is desirable. This document contains no regulatory policy and does not obligate systems to use any treatment or nontreatment technique to reduce nitrate concentrations.

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NITRATE REMOVAL FOR

SMALL PUBLIC WATER SYSTEMS

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I. SUMMARY AND OVERVIEW

PURPOSE

This Handbook for Nitrate Removal has been prepared to aid water utility owners, engineers, operators, and municipal managers in understanding and dealing with excessive nitrate levels in their water supply. It is intended to be used for defining the problem, developing or evaluating proposed solutions, and explaining to water consumers why nitrates are controlled and what the approximate costs of control will be. Although the handbook may be useful to larger utilities, it is intended primarily to support the water quality improvement efforts of smaller utilities that may lack the technical and financial resources of the larger systems.

This handbook is designed as a technical guide to nitrate removal for those smaller size systems that have decided that nitrate control is desirable. This document contains no regulatory policy and does not obligate systems to use any treatment or nontreatment technique to reduce nitrate concentrations. If appropriate, those regulatory requirements are or will be established by the primacy agency as part of its implementation of the Primary Drinking Water Regulations.

The handbook is divided into seven sections, plus references, as follows:

Section	Subject
I	Summary and Overview
II	Introduction - Discusses nitrate sources and origin of nitrate in drinking water, health effects, federal laws, and methods for detecting nitrate in water
III	Nontreatment and Treatment Alternatives - Different approaches to solving excess nitrate problems.
IV	Design of Nitrate Removal Systems - Ion exchange system types, suppliers. Example of design calculations. Waste disposal.
V	Cost Estimating Procedures and Funding Sources - Capital capacity. Sources of loans, grants and other financial assistance.
VI	Operation and Maintenance - Basic guidelines for operating nitrate removal systems, including water quality monitoring and equipment maintenance.
VII	Case Histories - Experience of two utilities which are treating the water supply to remove excess nitrates.

WHEN NITRATES ARE A PROBLEM

Nitrate is both a natural and a synthetic ion which is made up of one nitrogen (N) atom and three oxygen (O) atoms; its chemical symbol is (NO_3^-). Under natural conditions, nitrate usually does not occur

in drinking waters at levels which are of concern to water utilities. However, heavy use of nitrate fertilizers, septic tanks for sewage disposal, or animal feedlots may cause high local levels of nitrates in soils. Rainfall then washes the nitrate from the soil into streams and groundwater which may then contaminate these sources of drinking water supplies.

Beginning in the late 1940s, health research linked high levels of nitrates in drinking water with an illness called methemoglobinemia, a type of anemia. Victims of the disease were likely to be very young babies. About forty deaths were attributed to the disease, largely as a result of feeding babies with polluted well water. Based on these findings, the 1962 Public Health Service Drinking Water Standards set a maximum limit of 10 milligrams of nitrate-nitrogen per liter of water (mg/l NO_3-N) in public water supplies. Further reasearch supported this standard which was adopted unchanged in the National Interim Primary Drinking Water Regulations.

ALTERNATIVE METHODS USED TO REDUCE EXCESS DRINKING WATER NITRATES

If nitrates in the drinking water supply exceed 10 mg/l (or 20 mg/l for certain non-community systems) steps to reduce the level to 10 mg/l or less are generally recommended. Figure 1 depicts the steps recommended to define and eliminate nitrate problems. As explained later in this text, treatment for nitrate removal may involve significant costs. Before buying a nitrate removal system, the utility should also study all nontreatment approaches.

Often, nitrate problems are limited to one well or stream, or a localized land area. An alternate source of water may eliminate the problem. Cooperation and regionalization options that may be useful are discussed in the following reference:

> Regionalization Options For Small Water Systems U.S. EPA Office of Drinking Water, 401 M St., SW Washington, DC 20460.

It may also be possible to blend a water containing excessive nitrates with one having little or no nitrates to produce a blended water of acceptable quality. It may also be possible to reduce the nitrate concentration with time by controlling the source of contamination. For example, more careful application of nitrogen containing fertilizers or elimination of septic tanks may reduce contamination of ground water supplies in time. This is supported by a statistical comparison of nitrate concentrations from wells for a sewered area that previously contained septic tanks. The comparison showed significantly decreasing nitrate concentrations over the long term.(18)

TREATMENT METHODS

At the present time, nitrate removal can generally be achieved by two classes of treatment technologies: anion exchange and membrane processes such as reverse osmosis. At the present time, membrane systems and membranes per se are evolving and improving rapidly. Because of their relatively high cost

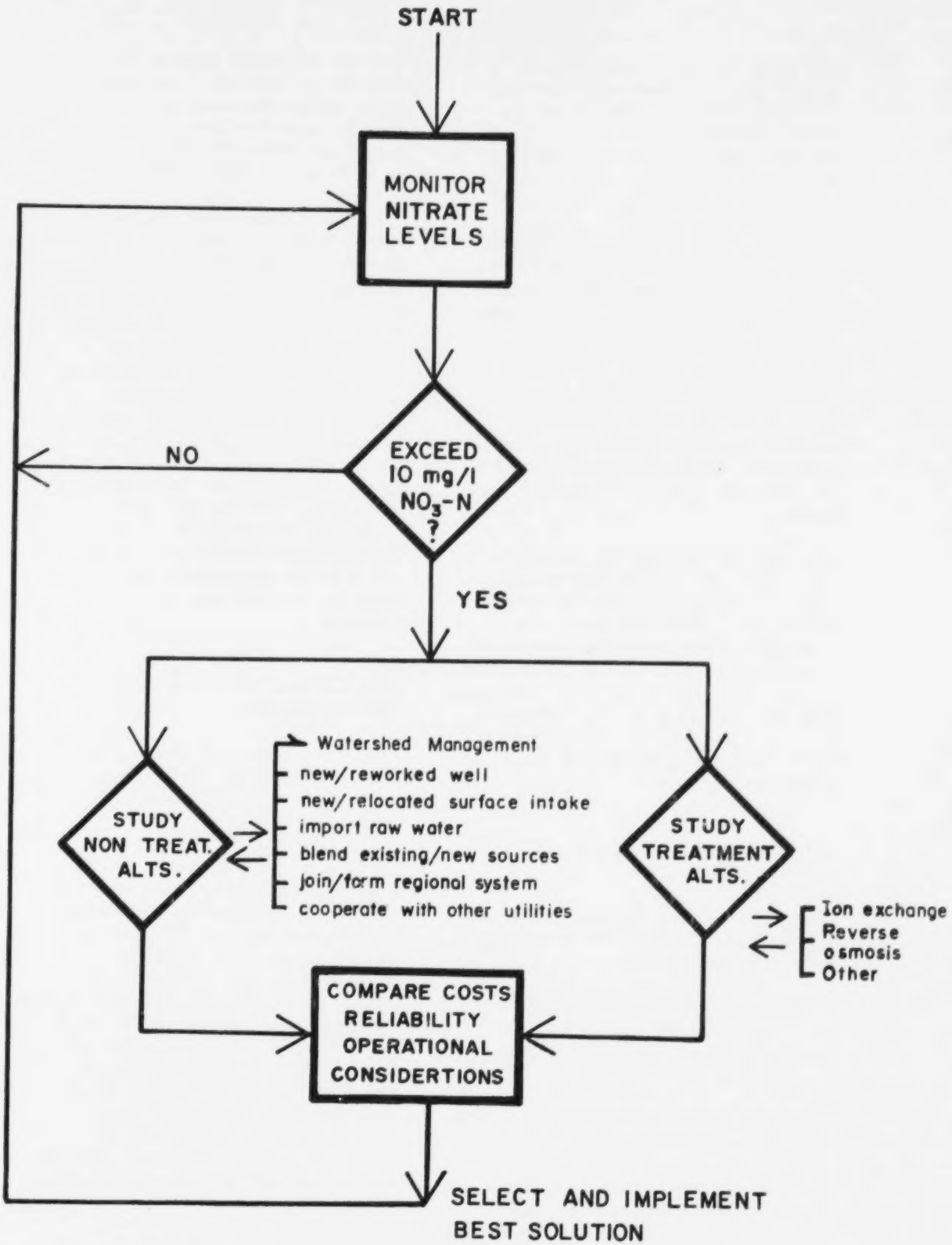


Figure 1. Nitrate Control for Community and Non-community Water Systems

and need for more sophisticated operation, membrane systems have not been routinely employed in small systems specifically for nitrate removal. Accordingly, this document will not discuss and detail information on these systems. It should be noted, however, that these processes may be particularly applicable to those water systems that contain excessive nitrate concentrations and contain high concentrations of dissolved solids or other undesirable consitutents. Reverse osmosis information is provided in a document titled: "Radionuclide Removal for Small Water Systems" currently being prepared by U.S. EPA Office of Drinking Water.

The ion exchange processes use equipment and technologies similar to those used for home water softeners. This equipment is available from numerous suppliers, a partial list of which is provided in Tables 5 and 6 of this handbook. Figure 2 depicts the ion exchange unit at Curryville, Pennsylvania that has been adapted for nitrate removal.

DESIGNING AN ION EXCHANGE NITRATE REMOVAL SYSTEM

Design of an ion exchange system for nitrate removal involves two main considerations:

1. Characterization of the water to be treated and selecting the ion exchange resin.

2. Designing the tanks, plumbing and controls.

The ion exchange resin is the heart of the process. In the resin bed, located in the exchanger tank as shown in Figure 3a, nitrate is removed from the water by an exchange process whereby nitrate ions in the water are replaced by chloride ions from the resin bed.

When the replacement or exchange capacity of the bed is exhausted, it must be regenerated by pumping a brine solution (usually sodium chloride, NaCl) from the brine tanks through the resin bed (Figure 3b). The resin tanks, brine tanks and plumbing are sized depending on the amount of nitrate to be removed, the presence of competing ions particularly sulfate, and the characteristics of the resin selected. The design procedure is based on manufacturer's recommended parameters which can also be determined and possibly optimized, by pilot testing.

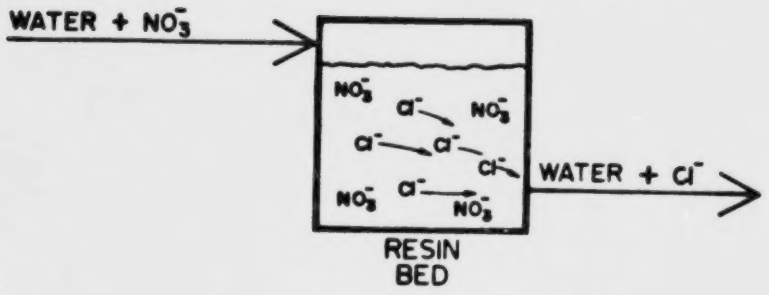
COST ESTIMATING PROCEDURES AND FUNDING SOURCES

Section V explains the procedure that can be used for estimating treatment and operation and maintenance costs.

Currently (1981), there is only one nitrate removal ion exchange system in continuous operation in the continental United States at a water utility. This system, operating at less than 10% of its nominal 40,000 gpd capacity, was installed in 1979 for $30,000. (See Section VII for Details.) Costs cited in the examples provided in this handbook are estimated data generated from a variety of sources. Adjusting cost figures for inflation is also discussed in Section V.

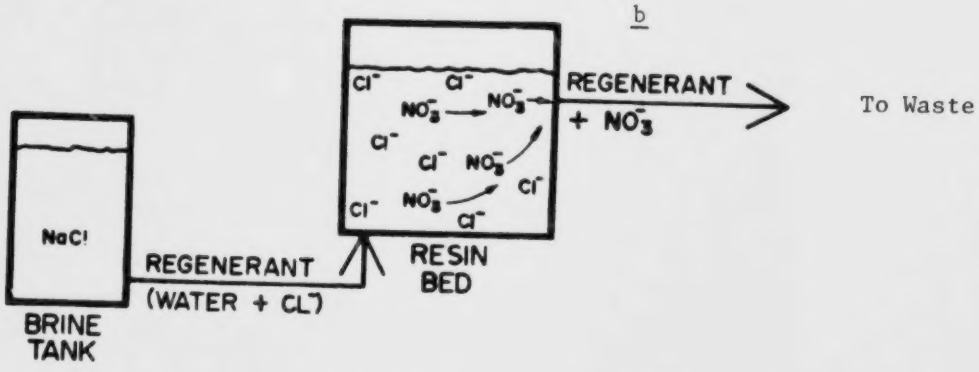
Figure 2. Ion Exchange Unit at Curryville, Pennsylvania

a



Removing NO_3^- from the Water

b



Regenerating the Resin Bed

Figure 3. The Ion Exchange Process

Sources of financial assistance, in the form of loans, loan guarantees, or outright grants, are very limited. The principal federal financial assistance programs available are shown in Table 1.

OPERATION AND MAINTENANCE OF NITRATE REMOVAL SYSTEMS

In general, ion exchange systems for nitrate removal share the very low maintenance requirements of similarly sized water softeners. Regeneration is initiated by simple, highly reliable flow meters and controlled by timers and automatic valves known for their trouble-free operation. Unlike water softeners, which are designed to treat a nuisance--hard water, nitrate ion exchangers are designed to remove a substance capable of producing a health hazard--nitrate. Thus, the nitrate ion exchangers require more safeguards in their design and operation. This generally includes a requirement for the ability to monitor for nitrate breakthrough. Even so, operator time required to run the system will not exceed several hours per day in most cases. Operators do not require highly specialized skills, but they must understand fundamental chemistry and be able to perform accurate nitrate analyses and be familiar with pumps, controls, plumbing and electrical systems and know how to keep basic records.

SUMMARY

Systems faced with the need to reduce excessive nitrates in the water supply can use a variety of nontreatment approaches, or install a treatment system. This handbook describes the design steps used for developing a simple, reliable and cost effective system for nitrate control. Suggestions for nontreatment approaches by individual water utilities are also offered and a reference that discusses nontreatment approaches in detail is provided.

TABLE 1

FEDERAL FINANCIAL ASSISTANCE PROGRAMS

Agency	Program Description
Farmers Home Administration	1. Cooperative grants up to 75 percent of project cost for publicly owned rural systems serving fewer than 10,000 persons. 2. Loan guarantees up to 90 percent of loan face value for public or private rural utilities, emphasizing those serving fewer than 2,500 persons. 3. Direct loans up to 75 percent of project cost.
Department of Interior	1. Direct loan programs for non-federal entities in the 17 western states. 2. Financial assistance for systems serving American Indians.
Department of Housing and Urban Development	1. Community Block Development Grant Program

II. INTRODUCTION

NITRATE: WHAT IT IS AND WHERE IT COMES FROM

Nitrate is a nitrogen-oxygen ion that occurs frequently in nature as the result of the interaction between nitrogen in the atmosphere and living things on earth. This interaction is described pictorially by the nitrogen cycle (Figure 4).

decay, the nitrogen compounds are constantly cycled among various forms. When plant and animal proteins are broken down by digestion or decay, ammonia (NH_3) and nitrogen gas (N_2) are released to the atmosphere or to the land. Ammonia in the air is returned directly to the earth in rain, as it readily combines with water. Nitrogen

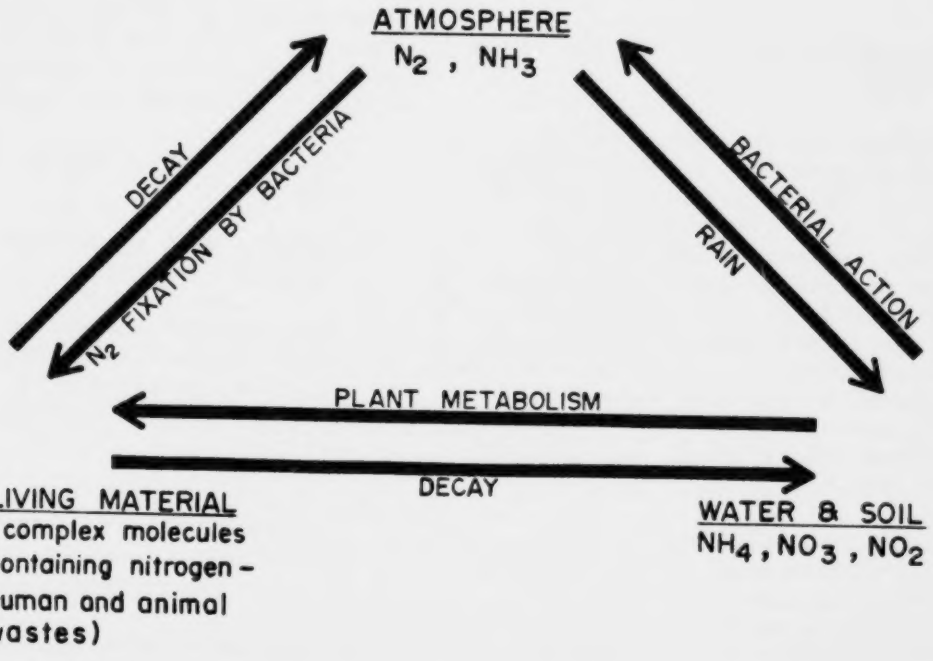


Figure 4. The Nitrogen Cycle

At any time, nitrogen gas and its compounds with hydrogen and oxygen exist in the atmosphere, on the surface of the earth, and in the soil. Through the action of plants, animals, and the microscopic organisms that effect

gas is taken from the air and converted to proteins and other compounds containing nitrogen by nitrogen fixing bacteria that live on the roots of a class of plants called legumes (e.g., alfalfa). The action of

lightning in storms and high temperature combustion processes cause nitrogen and oxygen to combine to nitrous oxide (NO) which quickly oxidizes to nitrogen dioxide (NO_2). The latter combines with rain water to form nitrates (NO_3^-) and nitrites (NO_2^-) which soak into the soil. The cycle is completed by plants which take the nitrogen compounds from the soil and, through photosynthesis, create plant proteins which man and animals then digest and decay, releasing ammonia and nitrogen gas anew.

NITRATES AND HEALTH: WHY THE CONCERN

Nitrogen and its compounds are clearly necessary in human metabolism. Why then, are nitrates of concern in drinking water? The answer is that, while we need some nitrate to live, too much is not beneficial. In other words, if people and animals consume food or water that contain excessive nitrate, it can make them sick. Left untreated, nitrate caused illness can be fatal, particularly for the very young.

The illness resulting from too much nitrate usually takes the form of methemoglobinemia, in which nitrates interfere with the body's ability to take oxygen from their air and distribute it to body cells. Bacteria that are normally present in the body convert ingested nitrate (NO_3^-) to nitrites (NO_2^-), which in turn replace oxygen in the blood. This condition is exhibited as a type of oxygen starvation, similar to anemia. The victim often takes on a pale, bluish coloration. If not recognized and treated, death can result, particularly if the victim is an infant.

Methemoglobinemia was first identified with polluted drinking water supplies by H. H. Comly of the U.S. Public Health Service in 1949.[2] Further work firmly established the connection[3] and led to the 1962 U.S. Public Health Drinking Water Standard for nitrates. The standard was adopted without major changes in the Interim Primary Drinking Water Regulations that resulted from the Safe Drinking Water Act.

A 1974 study for the State of Illinois[4] reviewed the PHS standard and noted that certain groups of people are more vulnerable to nitrate induced sickness, including the following:

1. Infants under 3 months in age
2. Infants with respiratory illness or diarrhea
3. Individuals with enzyme deficiencies that increase their vulnerability to nitrate ingestion related illness
4. Individuals with a lack of free hydrochloric acid in the stomach (achlorhydria) due to gastric diseases

This study noted that methemoglobinema can occur in infants at relatively low nitrate conditions when the other contributing factors are present. Table 2, published in the Illinois study from another work,[5] illustrates this point.*

---

* These data are drawn from the earlier work by Walton[3] and the American Public Health Assocation[6] and summarized by Lee[5].

TABLE 2

OCCURRENCE OF NITRATE INDUCED ILLNESS VS. NITRATE CONCENTRATION[5]

State	Methemoglobinemia Reported Cases	Reported Deaths	Number of cases associated with indicated ranges of nitrate/nitrogen (ppm) 0-10	11-20	21-30	31-50	51-100	100+	Number of cases for which data are available
California	1	0	0	0	0	0	1	0	1
Georgia	6	3	-	-	-	-	-	-	0
Illinois	75	6	0	1	2	2	12	11	28
Indiana	1	0	0	0	0	0	3	0	1
Iowa	Several	11	0	0	0	0	1	1	2
Kansas	13	3	0	0	1	1	2	8	12
Michigan	7	0	0	0	0	0	0	7	7
Minnesota	139	14	0	2	25	29	53	49	129
Missouri	2	0	0	0	0	0	0	2	2
Nebraska	22	1	0	1	0	4	9	8	22
New York	2	0	0	0	0	0	1	0	1
North Dakota	9	1	0	1	1	0	0	5	8
Ohio	0	0	0	0	0	0	0	0	0
Oklahoma	0	0	0	0	0	0	0	0	0
South Dakota	Several	0	-	-	-	-	-	-	-
Texas	0	0	0	0	0	0	0	0	0
Virgina	1	0	0	0	0	0	1	0	1
	278	39	0	5	29	36	83	91	214

The National Academy of Science documented in its recent report "Drinking Water and Health,"[7] that nitrates in food and drinking water have also been implicated in the formation of nitrosamines, known human carcinogens. It is theorized that nitrates are reduced to nitrites by bacteria in the body, with nitrites then available to combine with naturally occuring amines in the stomach to produce the carcinogen.[8] However, there is no evidence directly relating human cancer to nitrates in drinking water and this point is raised here only to underscore the advisability of limiting nitrate consumption from water and other sources.

HOW NITRATES GET INTO WATER SUPPLIES

Nitrates occur in our bodies, our foods, and the plants, animals and soils around us. Normally, nitrate concentration is limited by the natural action of the nitrogen cycle, avoiding buildup to levels of

concern in water supplies. Runoff from undisturbed natural areas rarely contain more than a trace of nitrates. Ground waters from the same areas approach nitrate free conditions.

Human interaction with and alteration of the environment can create elevated nitrate levels in streams and wells. Figure 5 illustrates some of the routes contamination can take. Agricultural activities, such as fertilizer use and animal feedlots, can cause substantial quantities of ammonia and nitrate to be washed off and through the soil with rainfall. The nitrate polluted water can then flow into local streams or percolate into ground water.

Use of septic tanks with drain fields in close proximity to ground water supplies is another important source of nitrate pollution. Reference 2 reported specifically on illness caused in infants from septic tank polluted ground water.

The severity of contamination caused by these sources can be increased if faulty well construction and protection practices provide a direct link to the ground water.

There may be other isolated sources of nitrates in water supplies. However, fertilizer and septic tanks have been found to be the most common sources.(4) Hence a community water system drawing its raw water from sources likely to be affected by these factors should be particularly alert to the possibility of nitrate pollution.

THE SAFE DRINKING WATER ACT

The Safe Drinking Water Act (SDWA) became law on December 16, 1974. It directed the U.S. Environmental Protection Agency (EPA) to develop National Interim Primary Drinking Water Regulations (NIPDWR) which became mandatory for public water supplies, as defined below:

> "A public water system is any publicly or privately owned drinking water supplier with at least 15 service connections or which regularly serves at least 25 persons daily at least 60 days per year."

The regulations are being put into force into two stages:

- Interim Regulations - effective June 24, 1977
- Revised Regulations - effective as health studies on various contaminants are completed

The NIPDWR sections of prime interest to the small water system can be categorized as follows:

- Maximum contaminant levels (MCLs)
- Monitoring
- Record keeping
- Reporting
- Variances and exemptions
- Citizen's lawsuits
- Emergency powers
- Site requirements

The regulations apply to public water systems including both community and noncommunity water systems.

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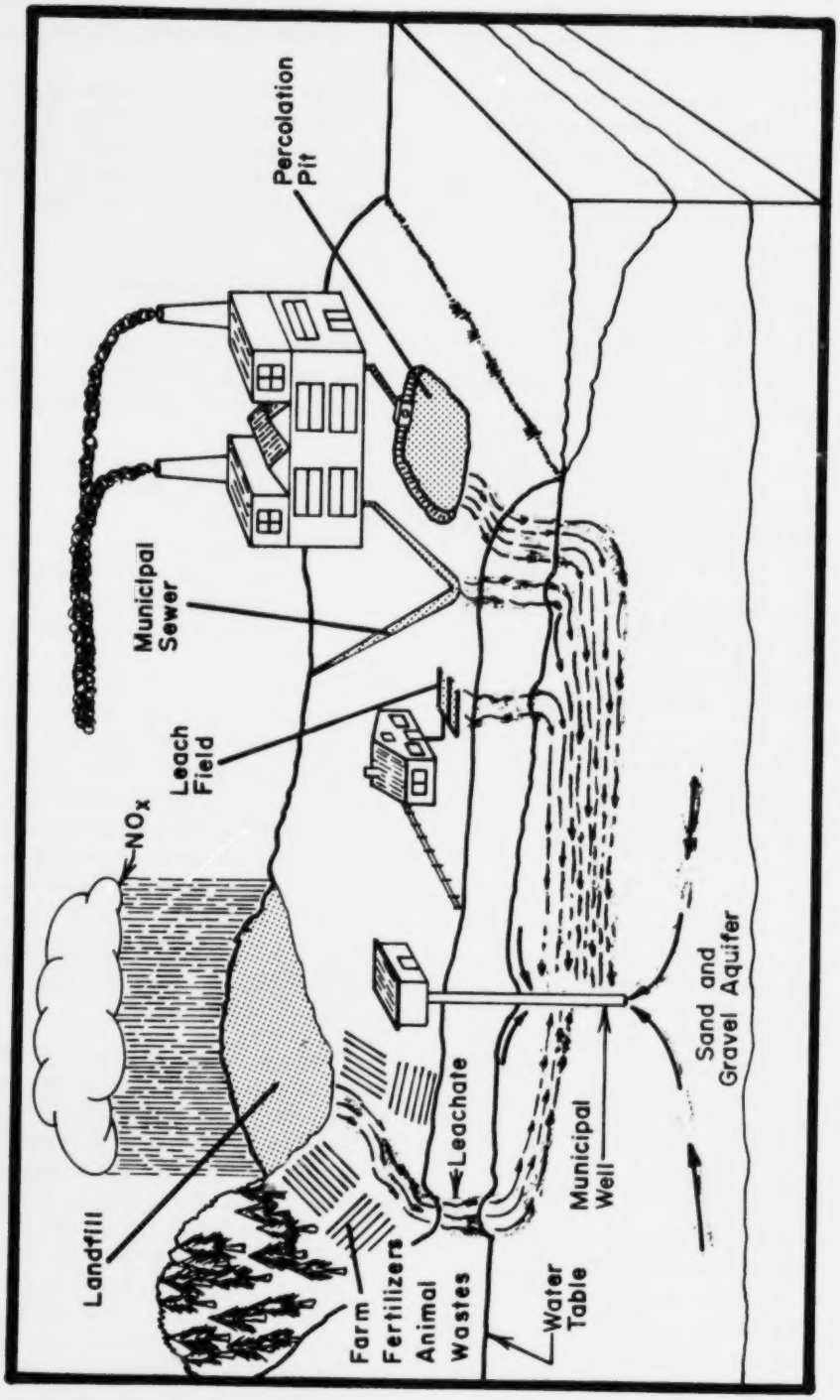


Figure 5. Typical Sources of Nitrates in Raw Water Supplies

A community system is a public water system which has at least 15 service connections used by year-round residents or regularly serves at least 25 year-around residents. Noncommunity water systems are public systems that serve travellers or other intermittent users for at least 60 days out of the year. The SDWA requires promulgation of minimum federal regulations. A state, in order to have primary enforcement responsibility (primacy) must have primary drinking water regulations at least as stringent as the federal regulations.

The NIPDWR adopted without change the limit for nitrate establishd in the earlier 1962 Public Health Service Drinking Water Standard:

> "Nitrate-nitrogen in the final treated water must be 10 milligrams per liter or less, as measured by laboratory analysis."

Since that time the regulations have been amended to establish a limit of 20 mg/l NO_3-N for noncommunity systems under certain conditions.

Any water supply covered by the SDWA must monitor and report nitrate levels once per year, if using surface water, or once every 3 years, if using groundwater. States may, and often do, require more frequent monitoring and reporting.

Recommended Reading

A detailed but concise synopsis of the Safe Drinking Water Act and the NIPDWR, written specifically for water system owners and operators is available:

The Safe Drinking Water Act--Self Study Handbook, Community Water Systems, available from the American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235.

Specific regulations applicable to a particular utility should be obtained from the agency that has primary enforcement authority under the SDWA.

ANALYZING FOR NITRATES

There are three general classes of analytical methods which can be used for nitrate analysis:

- o Laboratory tests using Standard Methods (U.S. EPA approved)
- o Packaged test kit (premeasured dry chemical)
- o Measurement with nitrate ion selective electrode

An EPA approved laboratory analysis must be used for complying with nitrate testing required by the EPA and state agencies. The other methods are useful for research or control of operating systems and can be useful because of their relative simplicity if a correlation to the results obtained by the approved test can be achieved.

Packaged Test Kits that can approximate nitrate levels quickly and inexpensively are available from a number of vendors (Table 3). Two nitrate test kits from Hach, Model NI-12 and NI-14 were tested and calibrated as part of the treatment study underway at McFarland, California.[89] The NI-12 is designed for use in the range of 1-50 mg/l nitrate (as nitrogen) while the N-14 is used in a range of 1-10 mg/l nitrate

TABLE 3
PARTIAL LIST OF U.S. SUPPLIERS OF NITRATE FIELD TEST KITS

Supplier	Address
F. S. Brainard & Co.	231 Penn St., Burlington, NJ 08016
Captial Controls Co.	Advance Lane, Box 211, Colmar, PA 18915
Hach Chemical Co.	Box 289, Loveland, CO 80537
Mid West Instrument	286 Executive Dr., Troy, MI 48084
Sherman Machine & Iron Works	26 E. Main Str., Oklahoma City, OK 73104
Taylor Chemicals Inc.	7300 York Rd., Baltimore, MD 21204
Virgina Chemicals Inc.	3340 W. Norflok Rd., Portsmouth, VA 23703

(as nitrogen). It was found for the water at McFarland, that the Hach kits tended to give readings on the high side; hence, the calibration curves shown in Figure 6 were prepared.[9] They are included here as an example of how field test kits can be calibrated. The field test kit's principal advantages are low cost, speed and ease of use. It is not a substitute for the accurate laboratory analysis required for MCL compliance monitoring and reporting. However, the kits do provide a valuable tool for checking and controlling system performance and are accurate to about ±5 percent when properly calibrated.

Nitrate ion selective electrodes are useful for checking nitrate levels under controlled, laboratory conditions. They require frequent calibration and the electrode is subject to interferences from chlorides, fluorides and many other substances. The electrode is therefore most useful for waters of low mineral content. Electrodes currently available are best applied at concentrations over 10 mg/l (as nitrogen).[10] Approved methods for nitrate MCL compliance analyses require laboratory facilities and trained personnel. Approved methods are published by EPA and are available upon request from the Agency or state organization which implements the SDWA.

Two references on EPA (NIPDWR) acceptable laboratory procedures are available:

- Standard Methods for the Examination of Water and Wastewater, available from the Water Pollution Control Federation, 2626 Pennsylvania Avenue, NW, Washington, DC 20037.

- Manual of Methods for Chemical Analysis of Water and Wastes,

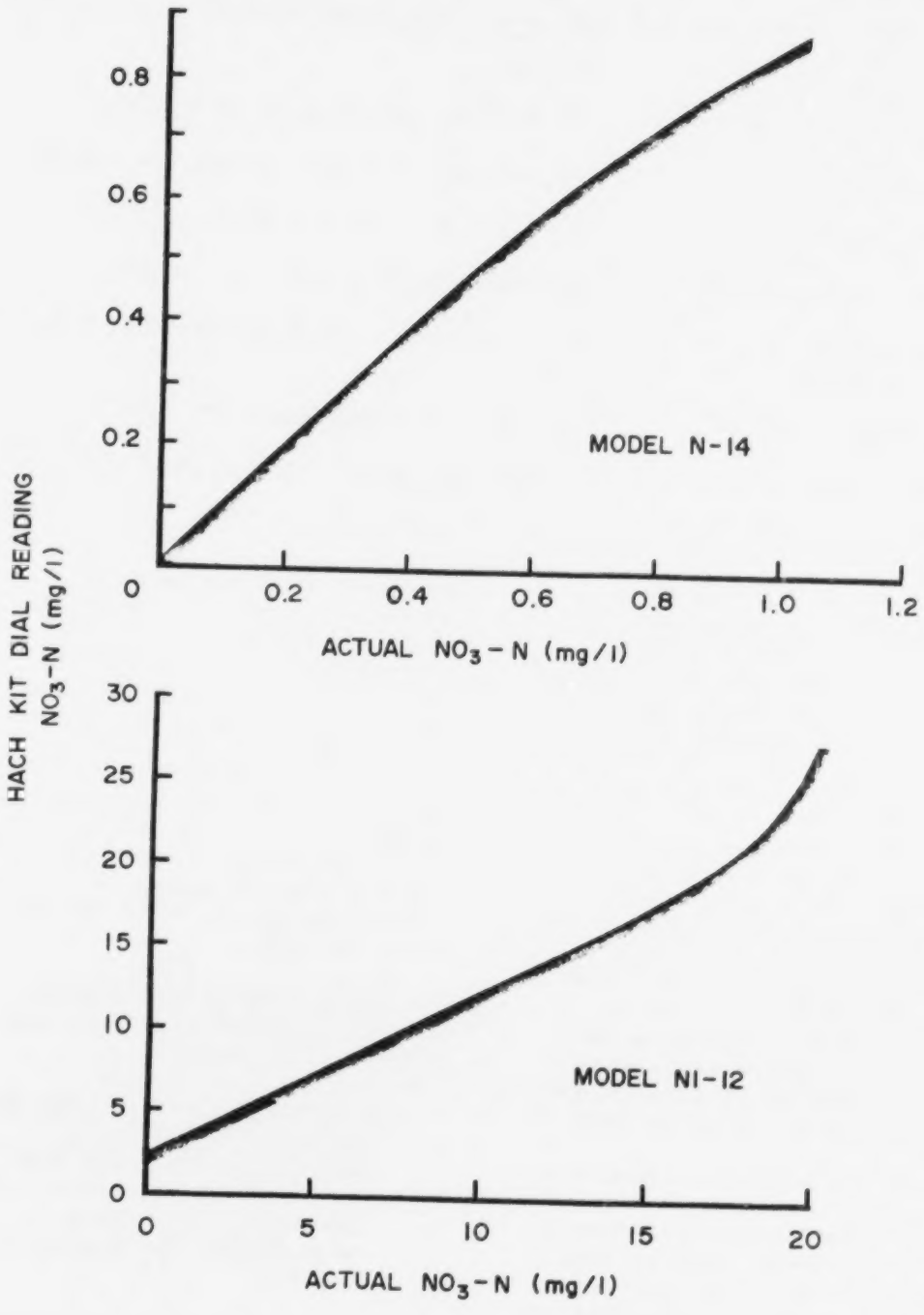


Figure 6. Hach Kit Calibration Curves Used at McFarland, California

available at no charge from the U.S. EPA, 26 West St. Clair St., Cincinnati, Ohio 45268.

A complete list of EPA-approved methods is available from the EPA or from the state agency that has primary enforcement responsibility for the SDWA.

UNITS OF NITRATE MEASUREMENT

When a laboratory analyzes drinking water for nitrate, it typically reports the results in the metric units of mass (milligrams) per unit volume (liters), milligrams per liter (mg/l) as nitrate-nitrogen (NO_3-N). In other words, the nitrate (NO_3^-) concentration is expressed as though it is in the form of nitrogen (N). The NIPDWR maximum contaminant level for nitrate is expressed in this manner as 10 mg/l NO_3-N.

How to convert nitrate analyses reported as nitrate to a result as nitrogen is explained in Section IV.

III. WHAT TO DO IF THE CONCENTRATION OF NITRATE IN THE WATER SUPPLY IS EXCESSIVE

If it has been determined that the nitrate concentration in the water supply is excessive, two general approaches to reduce the concentration should be evaluated:

- o Nontreatment alternatives
- o Treatment for nitrate removal

Each is discussed in this section. Economic and engineering data which further aid in the analysis of treatment and nontreatment alternatives is given in Section IV.

NONTREATMENT ALTERNATIVES

Four options are covered in this category:

- o Raw water source substitution
- o Blending with low nitrate waters
- o Connection to an existing regional system
- o Organizing a regional system

Inherent in all of these options is the usually correct assumption that the nitrate problem is localized. Thus, it may be possible to find acceptable ground water from other nearby wells or surface sources. Also, the existing well might be modified to draw water from different aquifiers (water bearing levels). Surface water users may find it feasible to draw from other streams, or may find that relocation of the intake will solve the problem. Substitution of sources should receive early consideration in the search for solutions. The MCL for nitrates applies to the water as it is delivered to the user. This means that water that exceeds the nitrate standard might be used if it is blended with other, low nitrate supplies. For example, a water supply could be made up of equal portions of two raw supplies containing 5 mg/l and 15 mg/l of nitrate-nitrogen respectively, and still meet the 10 mg/l standard.

It may also be cost effective to obtain all or at least a sufficient amount of water for blending from an outside supplier, perhaps a nearby city or regional system. Regional systems are becoming more attractive as their advantages become more apparent. Larger systems can spread the costs of water quality monitoring and analysis, and operation and maintenance, over a larger user base, thereby lowering per capita costs. The analysis of nontreatment alternatives is not complete without taking a look at regional alternatives. Joining an existing regional system, or forming a new regional utility by joining with other nearby systems which may be having similar water quality problems should be considered.

A broad range of regionalization alternatives is explained in the following reference:

Regionalization Options For Small Water Systems, U. S. EPA Office of Drinking Water, 401 M Street SW, Washington, DC, 20460.

It should be noted that whether a source of water high in nitrates is treated to reduce the nitrate or blended to reduce the nitrate, a failsafe

monitoring system should be incorporated into the design and operation of the system. This will protect users in the event the treatment or blending process malfunctions. It is also important to note that water sources high in nitrate point to the possibility that the sanitary quality of the source is in question. This aspect of the problem should be investigated. The agency with primary enforcement authority could be requested to perform a sanitary survey leading to recommendations for future action to resolve the entire water quality problem.

TREATING WATER SUPPLIES FOR NITRATE REMOVAL

Nitrate can be removed from drinking water reliably using currently available technology. It is not removed by the standard water treatment processes, such as coagulation, settling, filtration, carbon adsorption, chlorination or ozonation. Thus, nitrate removal generally requires installation of specialized equipment for either new or existing plants.

Six technologies for nitrate removal have or are being studied by public and private researchers:

- o Ion exchange
- o Reverse osmosis
- o Electrodialysis
- o Biological denitrification
- o Chemical reduction

Of these, only ion exchange has at this time been applied successfully to full scale drinking water systems specifically for nitrate removal. Reverse osmosis and electrodialysis have been applied primarily for desalting saline or brackish waters and will also remove 60 to 70 percent of nitrates. At this time, captial and operating costs for both processes exceed that for ion exchange under most conditions.[11] However, site specific conditions, such as in areas where brine disposal is difficult or where other constituents require reduction, may make these the systems of choice. In addition, these technologies are evolving and improving and their effectiveness and costs may change substantially in the near future.

The remaining processes listed above, chemical reduction and biological denitrification, must be regarded as experimental (although, biological denitrification is being considered in England for removal of nitrate from surface water[19]). This document focuses on ion exchange theory, design and methods of cost approximation. As more experience becomes available on the other technologies, this handbook may be updated. Specific information on reverse osmosis systems is provided in a document entitled "Radionuclude Removal for Small Water Systems" currently being prepared for EPA ODW.

How Ion Exchange Works

Ions in water are molecules or particles that exist in solution as semi-independent, electrically charged entities that can give noticeable properties to water. For example, calcium and magnesium ions, denoted as Ca^{++} and Mg^{++} are largely responsible for the characteristic called hardness. The higher the concentration of these positively charged ions, the harder the water. Ion

exchange technology was developed largely out of the desire to control hardness and its undesirable effects.

Overall, any water solution has to be electrically balanced; i.e., the solution must contain the same number of positively charged ions (cations) as negatively charged ions (anions). The most common cations are calcium (Ca^{++}), magnesium (Mg^{++}) and sodium (Na^{+}) and the most common anions are chlorides (Cl^{-}), bicarbonate (HCO_3^{-}) and sulfates ($SO_4^{=}$ or HSO_4^{-}). Nitrate (NO_3^{-}) is an anion as well.

Ion exchange treatment does exactly as the name implies: it trades one ion for another. The exchange process can be tailored to remove cations, by cation exchange, or to remove anions, by anion exchange. The latter process is used to remove nitrate from water solutions.

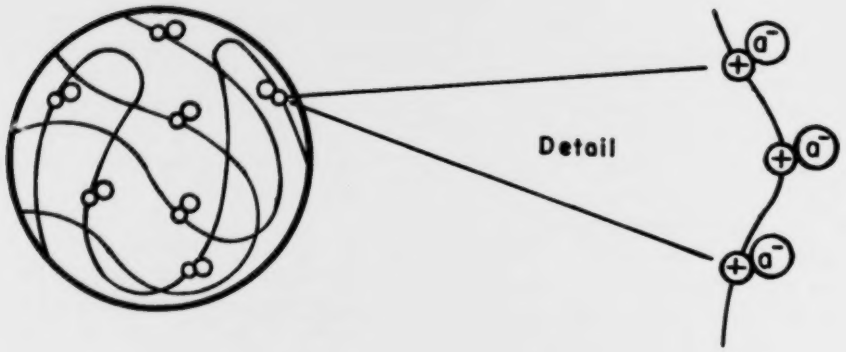
The actual removal of the nitrate ion occurs in a bed of ion exchange resin through which the water is passed. Resin beds are made up of millions of tiny, spherical beads which usually are about the size of medium sand grains. The resin beads are very homogeneous in size and color. Each bead (Figure 7) is, in effect, a skeleton on which exchange sites are available. The ion exchange media or resin bed is enclosed in an ion exchanger which consists of the tanks, piping, valves, monitors and controllers needed to operate the process.

Figure 8 depicts the full cycle of the ion exchange process as it would occur in an individual bead of resin. The process proceeds in four stages:

- In Stage I the ion exchange resin is fully recharged, or regnerated, and ready to remove ions.
- In Stage II the ion exchange resin is exchanging chloride ions for sulfate and nitrate ions, releasing chloride ions into the water and retaining sulfate and nitrate.
- In Stage III all of the exchange sites have been used up and the resin is said to be "exhausted" or "spent."
- In Stage IV the resin is "regenerated" by passing a strong salt water (brine) solution of sodium chloride (NaCl) through the resin bed. The very high relative chloride concentration displaces the sulfate and nitrate ions from the exchange sites on the resin beads. After a short washing to remove the salt water from the resin, the resin is ready to operate again, at Stage I.

Out of this highly simplified scheme of anion exchange, some points need particular emphasis:

- Ion exchange does not break up or convert the nitrate to another form. It merely removes it from the product water and deposits it first on the resin then ultimately in the spent reagenerant (water brine) stream during the regeneration cycle.



Long-chain organic molecule has positive charged sites (⊕) to which exchangable anions (⊖) are "loosely" bonded. In our example, the exchangable anions are chloride (Cl^-), which exchange for nitrate (NO_3^-).

Figure 7. Bead of Ion Exchange Resin

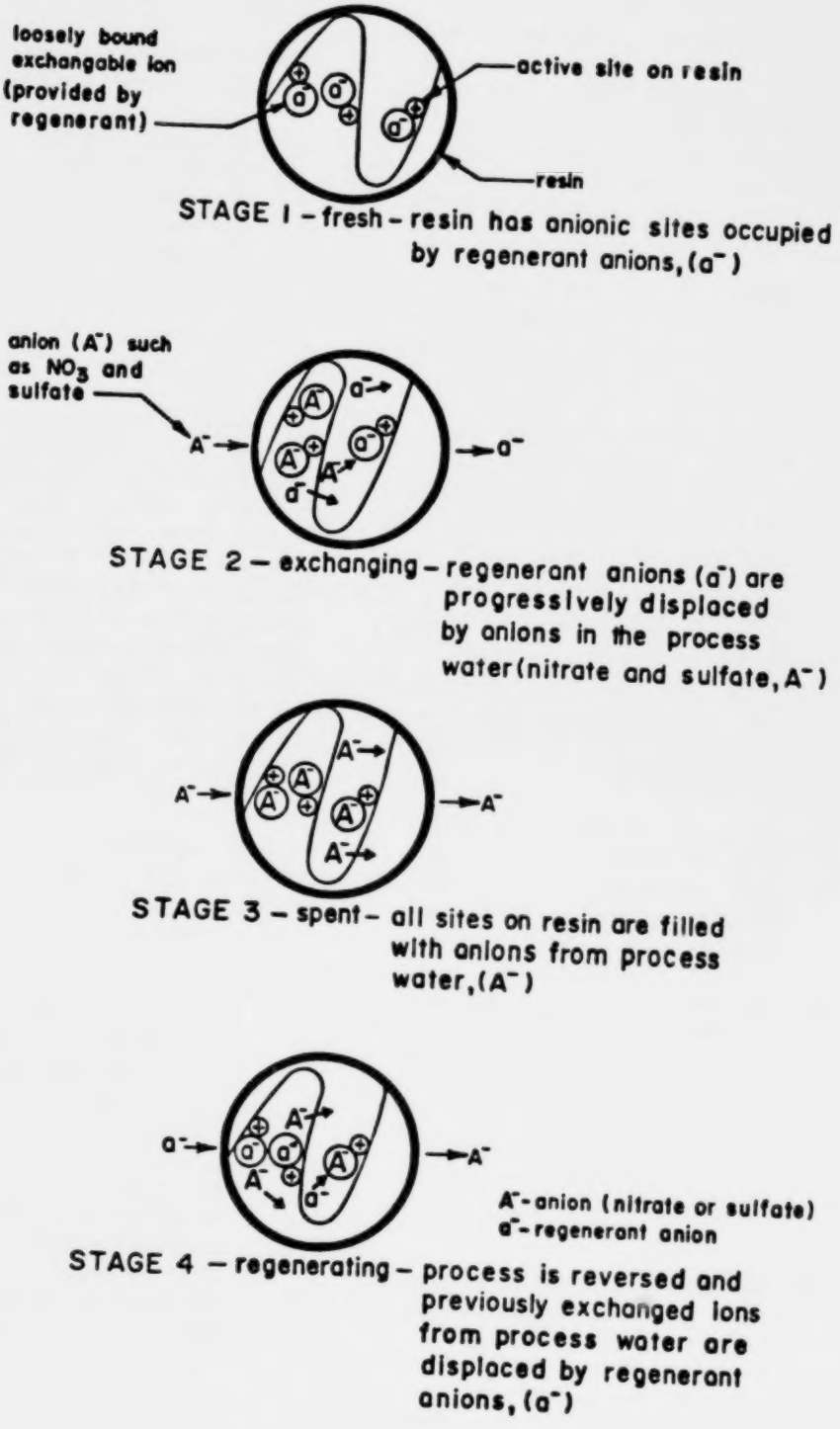

loosely bound exchangable ion (provided by regenerant)
active site on resin
resin
STAGE 1 – fresh – resin has anionic sites occupied by regenerant anions, (a⁻)
anion (A⁻) such as NO3 and sulfate
STAGE 2 – exchanging – regenerant anions (a⁻) are progressively displaced by anions in the process water (nitrate and sulfate, A⁻)
STAGE 3 – spent – all sites on resin are filled with anions from process water, (A⁻)
A⁻ – anion (nitrate or sulfate)
a⁻ – regenerant anion
STAGE 4 – regenerating – process is reversed and previously exchanged ions from process water are displaced by regenerant anions, (a⁻)

Figure 8. Ion Exchange Process Cycle

- Ion exchange produces a waste flow which must be disposed of. The waste flow is about 4 to 10 percent of the treated flow. Approximately 60 percent of the waste volume consists of concentrated (10-12 percent) brine solution which must be disposed of properly.

- There are currently no commercially available anion exchange resins that remove nitrate selectively over other anions.* In fact, sulfate ions are removed first. Therefore, if an anion exchanger is operated beyond bed exhaustion without regeneration, sulfate will dislodge nitrate from the bed and force it back into the product water stream. Under this condition the product water can contain higher concentrations of nitrate than were originally present in the raw water.

- There are a number of substances which can foul an anion exchange bed including suspended solids, iron and organic compounds.

- The chloride concentration of the finished water will be increased proportionately to the amount of sulfate and nitrate removed.

* Research on special resins that preferentially remove nitrate over sulfate is being performed under US EPA cooperative agreement CR 808902-0. Results when available will be published.

Ion Exchange Resins for Nitrate Removal

There are five general classes of ion exchange resins:

- Strongly acidic
- Weakly acidic
- Weakly basic
- Strongly basic
- Ion specific

Acidic resins are used to remove cations. Basic resins are used to remove anions such as nitrate. The terms strongly and weakly relate to the strength of the ionic forces in the resin and their ability to exchange various ions. Strongly basic resins are recommended for use in nitrate removal as they can effectively exchange nitrate from potable water at very low concentrations. Ion specific resins are formulated to maximize exchange of a target ion. There are currently no commercially available nitrate ion specific resins.

To be suitable for long term potable water service, an ion exchange resin should meet five basic requirements:(12)

1. It should have high total capacity as evidenced by its ability to exchange large numbers of ions throughout the volume of the bed.

2. It should have the proper chemical structure for the intended application. The resin should be designed to operate in the expected pH range with adequate selectivity to remove most of the target ions without being overly difficult to regenerate.

3. It should be very insoluble in potable water. A major value of ion exchange resins lies in their reusability. Low solubility also avoids leaching of impurities into the treated product.

4. It should have good physical and chemical stability. It should resist attack by the regenerant or any substances in water. It should be capable of withstanding turbulence and abrasion within the bed and not be broken down by contact with the exchanger walls or plumbing.

5. It must be nontoxic and must not release organic compounds to the water stream. Many states require that resins used in potable water systems be approved by the state. EPA provides guidance to state primacy agents regarding acceptability of resins for use in potable water service. Resins approved for use by the Food and Drug Administration (FDA) in accordance with federal regulations 21 CFR 173.25 are generally acceptable for use in potable water systems.

Selectivity defines the affinity of a particular resin for a particular ion. It depends on ionic charge, molecular weight, and solution concentration. For a strong base resin in a weak solution, such as potable water, the resin selectivity would operate as shown in Figure 9. Thus, the resin would take up sulfate along with nitrate and would have some preference for the former. If the ion exchanger is operated beyond exhuastion, no more nitrate will be taken up and, in addition, sulfates will displace nitrates from the bed causing the bed effluent to have more nitrates than the influent. When designing a system, it is imperatitve that this operating characteristic be recognized and adequate safeguards be provided.

There are currently four major resin producers in the United States. They all distribute resin under their own and other trademarks (Table 4). All currently provide strongly basic resins for nitrate removal.

Ion Exchange Plant Description

The term "plant" as used here describes the tanks, piping, valving, monitors, controllers and other hardware needed to operate the ion exchange bed. Two types of plants are currently available in the U. S.

- o Fixed bed exchangers
- o Continuous ion exchangers

Fixed bed exchangers, shown in Figure 10, are the units most commonly used for industrial and private systems. The home water softener follows the same basic design. The unit is controlled by a flow totalizer which is set to initiate an automatic regeneration cycle at about 75 to 80 percent of the theoretical bed capacity. During regeneration, the regenerant is pumped through the bed for a preset period, followed by a rinse to cleanse the bed. Many systems also incorporate backwashing to "fluff" up the bed, remove trapped solids and thereby reduce pressure drop through the exchanger.

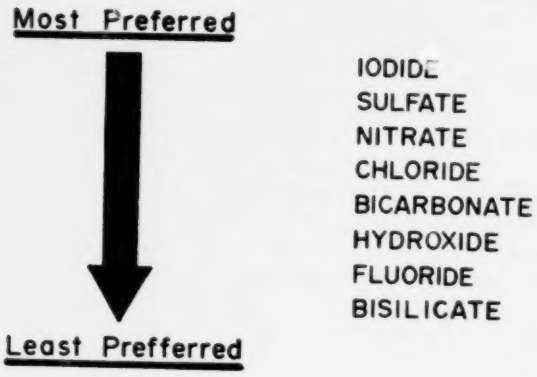


Figure 9. Selectivity of Strong Base Anion Exchange

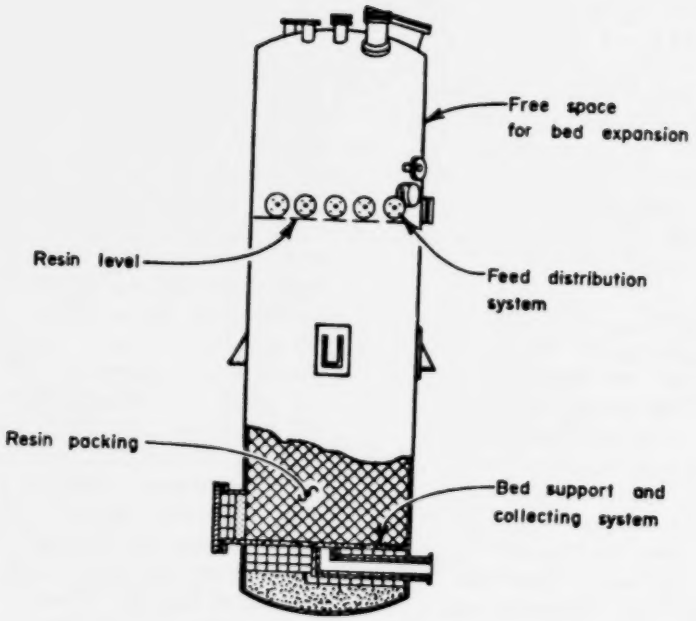


Figure 10. Fixed Bed Ion Exchanger[13]

TABLE 4

PARTIAL LIST OF U.S. ION EXCHANGE RESIN PRODUCERS

Company	Location	Trademark
Diamond Shamrock	Cleveland, Ohio	Duolite
Dow Chemical Company	Midland, Michigan	Dowex
Ionac Chemical Corporation	Birmingham, New Jersey	Ionac
Rohm and Haas Company	Philadelphia, Pennsylvania	Amberlite

A typical fixed bed exchanger usually consists of a cylindrical tank having four essential features:

- Sufficient space above the bed for expansion during backwashing.
- A feed distribution system to spread the influent water across the surface of the bed.
- A bed support system that collects the product water uniformly and prevents leakage of the resin.
- An internal lining that protects the containing vessel from corrosion from the process water and regenerating chemicals.

Where semi-continuous output is needed, the use of two fixed bed units, each sized for full flow, allows full operation on one bed while the second is being regenerated or is held in ready condition to replace the first when it becomes exhausted. Process interruption is limited to the few seconds needed to switch the process flow between beds.

Suppliers of fixed bed equipment are numerous, with equipment ranging in size from simple one-bed home water softeners to very large industrial and municipal systems. Some suppliers are listed in Table 5.

Continuous ion exchangers were developed for larger installations where continuous output is required and minimizing bed volumes is desired. While treating product water, these units periodically move the resin bed through a cycle in which a portion of the bed is withdrawn and regenerated outside of the main exchange vessel, while regenerated resin is returned in fresh condition. There are several versions of this equipment available in the U.S. (Table 6) and it has largely been applied to industrial water treatment problems.

Figure 11 (a and b) depicts the operation of the units provided by these two companies listed in Table 6. The Chemical Separations Corporation unit is based on the Higgins process and has been successfully applied to nitrate removal from drinking water in a 2.0 mgd installation at Garden City Park, New York.

TABLE 5

PARTIAL LIST OF U.S. SUPPLIERS OF FIXED BED ION EXCHANGE SYSTEMS

Company	Location
Culligan Company	Northbrook, Illinois
Envirex	Waukesha, Wisconsin
Graver Company	Ames, Iowa
General Filter	Clayton, New Jersey
Hungerford & Terry	Richmond, Virginia
Illinois Water Treatment	Rockford, Illinois
Infilco-Degremont	Richmond, Virginia
Ionics	Watertown, Massachusetts
Permutit Company	Paramus, New Jersey

TABLE 6

PARTIAL LIST OF U.S. SUPPLIERS OF CONTINUOUS ION EXCHANGE EQUIPMENT

Company	Location
Chemical Separations Corporation	Oak Ridge, Tennessee
Infilco-Degremont	Richmond, Virginia

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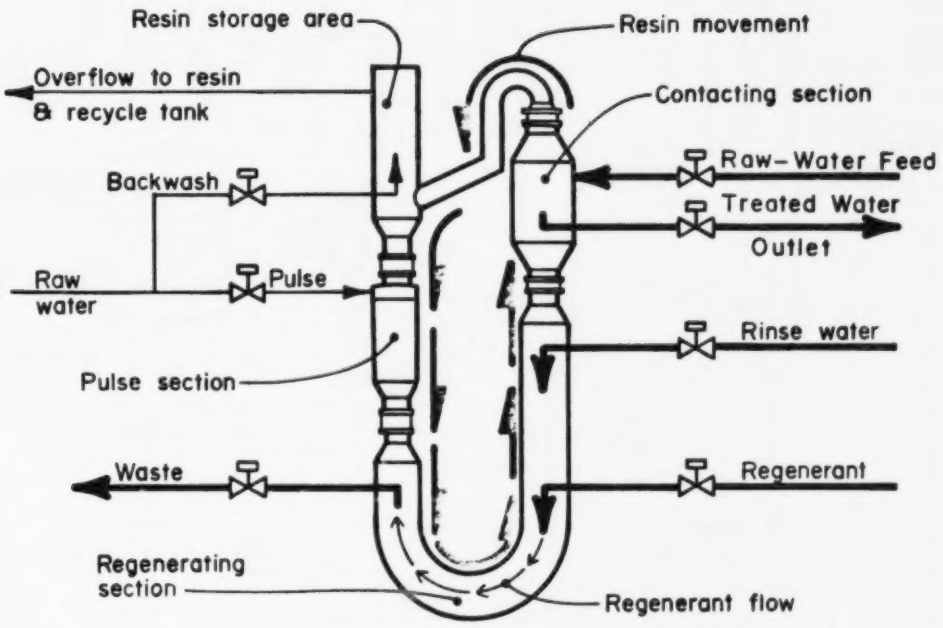
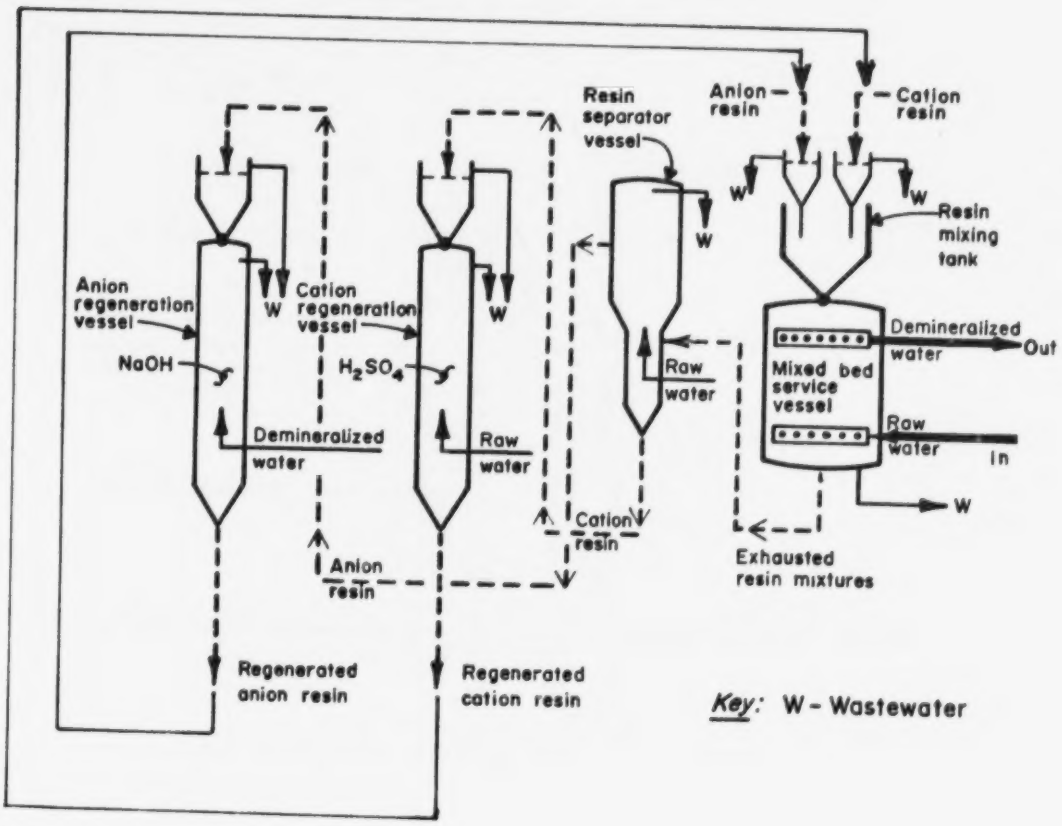


Resin is pulsed periodically in the hydraulically operated pulse section. As it travels around the exchanger, the resin passes through successive stages of backwashing, regeneration and process water treatment.

Figure 11a. Continuous Ion Exchange Process (Pulsed)



The anion and cation exchange resin mixture is continuously withdrawn from the bottom of the service (water treatment) vessel, and hydraulically separated into anion and cation resin regeneration vessels. In these vessels the anion and cation exchange resins are regenerated individually by the appropriate regenerants. The fresh resins are finally remixed in a resin mixing tank prior to being reintroduced to the service vessel.

Figure 11b. Continuous Ion Exchange Process

IV. DESIGNING A NITRATE REMOVAL SYSTEM

This section is intended as a primer covering the fundamentals for evaluating process proposals from design consultants and/or equipment vendors. The actual design will be a function of the raw water characteristics and flow, type of equipment selected and site requirements. Pilot testing to select a resin and to determine design parameters is recommended for larger systems as currently there is very limited design and operating experience with nitrate removal systems for domestic water supplies. Figure 12 illustrates the steps used to design the nitrate removal system.

ABBREVIATIONS, UNITS AND CONVERSION TABLES

The abbreviations and units used throughout this section are defined in Appendix A. Metric unit conversion tables are also provided. Units used in this document follow typical U.S. practice for ion exchange system design and general water supply.

ANALYSIS OF RAW WATER SUPPLY

The first step is to fully characterize the water supply and determine, where possible, the nitrate source. If the nitrates are entering the water supply as a result of inadequately treated sewage or septic tank leakage, continued use of the water supply may pose severe health risks other than those related to nitrates. Nitrate level as a function of time is also quite important. Increasing nitrate levels will shorten the run time between regenerations and may render system design obsolete, particularly where blending of treated and nontreated water is practical.

Raw water constituents of prime interest are shown in Table 7, along with their principal relationship to system design. Of course, the water should also be checked to determine if it is bacteriologically acceptable.

PILOT TESTING

Pilot testing, using scale model ion exchange reactors, is recommended by resin manufacturers to establish key design and operating parameters for individual systems. It is also generally advisable to perform a pilot study of treatment processes that are not well understood or not widely used in order to avoid costly errors in treatment process design. Pilot testing may be cost effective for larger systems or in situations where the water treatment problem is exceptionally difficult. Specific guidebooks for pilot testing are available from resin manufacturers (Table 8).

Extensive pilot testing of five strong base ion exchange resins has been carried out at MacFarland, California, using 2-inch test colums 4 feet in height containing 1,245 cubic centimeters (0.44 cu.ft.) of resin. This work, outlined in Section VII, (and described in detail in Reference 16) produced more

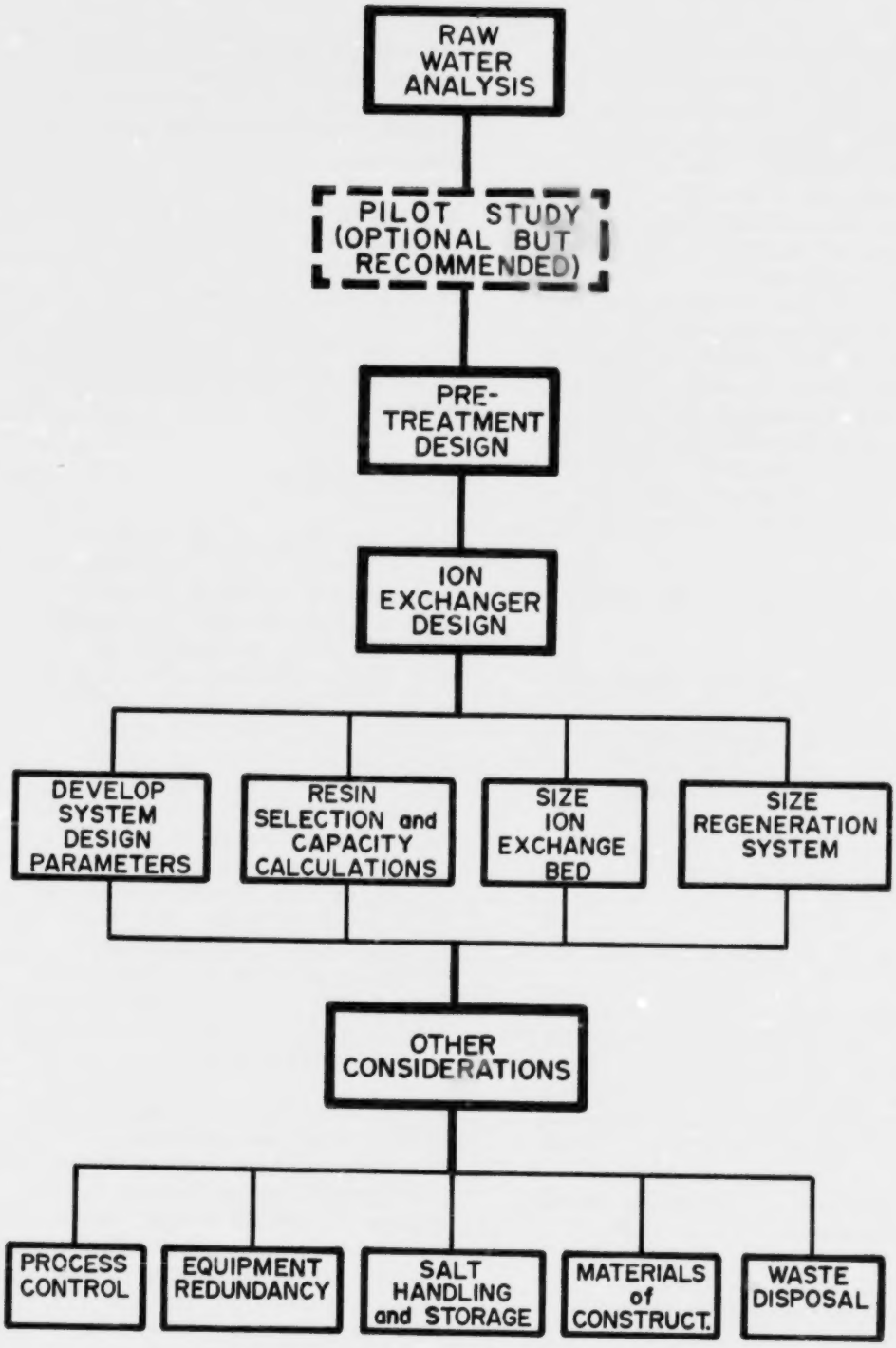


Figure 12. Nitrate Removal System Design Steps

TABLE 7

RAW WATER CONSTITUENTS THAT SHOULD BE QUANTIFIED

Name	Symbol	Why Needed
Bicarbonate	HCO_3^-	Interacts with strong basic resins
Nitrate	NO_3^-	To be removed
Sulfate	SO_4^-	Interferes with nitrate removal by competing for exchanged anions
Iron	Fe^{++}	Can coat resin and lower efficiency
Chloride	Cl^-	Released during exchange process, therefore, concentration increased by process
Suspended Solids	SS	May plug ion exchange bed
Total Organic Carbon	TOC	Some organics can foul resins

TABLE 8

SOME PILOT TESTING GUIDES AVAILABLE FROM RESIN MANUFACTURERS(9)

Company/Location	Guide/Author
Diamond Shamrock Functional Polymers Division 1100 Superior Avenue Cleveland, Ohio 44114	"Ion Exchange Polymers" I. M. Abrams, et.al.
Dow Chemical Company Functional Products and Systems Department Midland, Michigan 48640	"A Basic Reference on Ion Exchange" Dow Chemical Company
Rohm and Haas Fluid Process Chemical Department Philadelphia, Pennsylvania 19105	"A Laboratory Manual on Ion Exchange" "Amberlite Ion Exchange Resins Laboratory Guide"

optimized design parameters with resulting lower costs than those expected from the guidelines normally used by resin and ion exchange equipment manufacturers.

Ion exchange equipment suppliers will usually analyze a water sample and make recommendations for pretreatment requirements and anion exchange system sizing. The cost of this service is minimal, usually less than $50. In lieu of an on-site pilot study which may be uneconomical for very small systems, this alternative is recommended. Analyses and recommendations by at least two vendors is suggested. In addition, the Agency that implements the SDWA should be contacted for guidance and facility approval.

PRETREATMENT REQUIREMENTS

Ion exchange systems have one principal function--to exchange undesirable dissolved ions (such as nitrate) in the process water stream for ions which are less of a problem. They are not filters, even though some filtration may occur in the bed. Suspended solids, iron and organics are some of the more common contaminants that foul ion exchangers and for which pretreatment is required. These contaminants can occur in either surface or ground water.

Suggested action levels and pretreatment alternatives for common contaminants are shown in Table 9.

ANION EXCHANGE UNIT DESIGN

After detailed water analyses and identification of any pretreatment requirements, the nitrate removal (anion exchange) unit is designed. Largely, the design is based on nitrate concentration, total anion concentration (including nitrate and sulfate) and conservative design guidelines provided by the supplier of the exchange unit and/or resin. The specific design steps are outlined below using examples to illustrate actual computations required.

1. Develop system design parameters
2. Select resin and determine capacity
3. Size ion exchange bed
4. Size regeneration system

Develop System Design Parameters

System design parameters are based on known (or calculated) quantities such as required water production and nitrate reduction, combined with design assumptions. The process of defining the key design parameters is illustrated using examples below.

o SYSTEM OPERATING FLOW

Known Data:

- daily, weekly, monthly, seasonal and annual water production required.
- maximum, minimum and average raw water nitrate concentration.

Assumed Data:

- daily and weekly exchanger operating time.

TABLE 9

PRETREATMENT REQUIREMENTS FOR COMMON CONTAMINANTS

Contaminant	Action Level	Pretreatment Alternatives
Iron (Fe)	0.1 mg/l or greater as Fe	1. Chlorination to 1 mg/l residual followed by 20 minutes retention and sand filtration 2. Potassiuim permanganate treatment followed by filtration 3. Aeration in basin with 20 minute detention time followed by sand filtration
Suspended Solids	2 NTU* turbidity or greater	1. Sand filtration 2. If over 20 NTU, coagulation, settling, sand filtration
Organics	Any measurable concentration	1. Pilot test resin for fouling 2. Analyze for specific known interfering organics

* Nepholometric Turbidity Units

Calculated Data:

- blending ratio*
- flow rate through ion exchange unit.

Discussion:

Using standard design practice for consumer water demand for new systems, or measured flow data from an existing system, the flow rate through the ion exchange system is derived. The system is sized for flow based on maximum needs, considering adequate safety factors, and the possibility of blending. It will usually not be required to treat <u>all</u> of the flow to achieve the 10 mg/l NO_3-N standard. The anion exchanger will reduce nitrate to 0.5 mg/l NO_3-N. Accordingly, the effluent from the exchanger can be blended with the raw water thus reducing the volume that must be treated. Based on the utility's specific needs and capabilities, some assumptions about the ion exchanger operating schedule are needed. Unless the unit is operated continuously, to meet the instantaneous water demand, the operating schedule will

* Ratio of the treated flow rate to the total flow rate.

reflect the availability of maintenance and supervisory personnel, and the availability of finished water storage (reservoirs). Typically, a small system may elect to operate the unit during the normal 6 to 8 hour working day for 5 or 6 days a week, drawing on stored water when not operating. The System Operating Flow Example shows how to make these computations.

o WATER ANALYSIS DATA

Known Data:

- maximum concentrations of nitrate, sulfate, chloride, bicarbonate.

Calculated Data:

- total anion, sulfate and nitrate concentrations expressed in terms of a common base.

- ratio of sulfate and nitrate concentrations to total anion concentration.

- nitrates to be removed.

Discussion:

Water chemistry analytical results are typically given in terms of concentration, in milligrams per liter, as a function of the molecular weight of the particular compound. In order to compute total anions and anion ratios (needed for resin quantity calculations), all anions must be expressed to a common base. This is usually the equivalent weight, or since the concentrations are so low, the milliequivalent weights (milli = $\frac{1}{1000}$).

Table 10 provides equivalent weights for common water constituents. To obtain the number of milliequivalents per liter of a substance, its concentration in mg/l is divided by its milliequivalent weight ($\frac{mg}{meq}$).

Ion exchange resin capacity may also be given by the supplier's guides in units of grains of calcium carbonate ($CaCO_3$), per gallon; so, it may necessary to restate nitrate data in this form for later determination of ion exchange resin capacity. Since 1 grain equals 65 mg the conversions from grains to mg is made simply by multiplying grains by 65. Then the procedures in Appendix B can be used to determine the capacity in units of meq/l. The Water Analysis Data Conversion Example shows the procedure and general equations that are used to evaluate the required calculated data.

Resin Selection

Resin selection is a function of water analysis, pilot testing (if any) and manufacturer's recommendations. There are a number of strong base anion exchange resins available. Table 11 lists these resins and their suppliers. Considerable pilot test data on the performance of these resins is given in Reference 12. In addition, the manufacturers will provide detailed application guides for each resin. Factors to be considered in choosing the resin include initial cost and capacity, life, regeneration efficiency and pretreatment requirements.

TABLE 10

EQUIVALENT WEIGHTS

Compound	Equivalent Weight (Grams Equivalent)	Milliequivalent Weight (Milligrams Milliequivalent)
N	14.007	14.007
NO_3^-	62.005	62.005
Cl^-	35.453	35.453
SO_4	48.031	48.031
HCO_3	61.017	61.017
$CaCO_3$	50.045	50.045

TABLE 11

SOME STRONGLY BASIC RESINS AND THEIR SUPPLIERS(12)

Company	Resin
Diamond Shamrock Company	Duolite A-101-D
	Duolite A-102-D
	Duolite A-104
Dow Chemical Company	Dowex SBR-P
	Dowex SAR
	Dowex SBR
	Dowex 11
Ionac Division of Sybron Corp.	Ionac ASB-1
	Ionac ASB-1P
	Ionac ASB-2
	Ionac A-540
	Ionac A-550
	Ionac A-641
	Ionac AFP-100
Rohm and Haas Company	Amberlite IRA-400
	Amberlite IRA-402
	Amberlite IRA-410
	Amberlite IRA-900
	Amberlite IRA-910

SYSTEM OPERATING FLOW EXAMPLE

CALCULATION OF BLENDING RATIO AND ION EXCHANGER FLOW RATE
Known or Assumed Information:

Maximum daily flow	100,000 gallons/day
Maximum weekly flow	500,000 gallons/week
Maximum nitrate level	15 mg/l

1. Assume:

   The unit will be sized to treat the maximum daily flow of 100,000 gallons by routinely operating 6 hours per day, 5 days per week (presumes sufficient storage capacity for weekend demand).

   Produced water at 0.5 mg/l NO_3-N will be blended with untreated water at 15 mg/l NO_3-N to provide a finished water of 9 mg/l NO_3-N or less.

2. Calculate quantity of water which must be treated to produce 100,000 gpd of blended water with no more than 9 mg/l NO_3-N using the following general equation:

$$Q_{treated} = Q_{Total} - \left[Q_{Total} \times \frac{(\text{Final } NO_3\text{-N} - \text{Treated } NO_3\text{-N})}{(\text{Untreated } NO_3\text{-N} - \text{Treated } NO_3\text{-N})} \right]$$

   Therefore:

$$Q_{Treated} = 100{,}000 \text{ gpd} - \left[100{,}000 \text{ gpd} \times \frac{(9 \text{ mg/l} - 0.5 \text{ mg/l})}{(15 \text{ mg/l} - 0.5 \text{ mg/l})} \right]$$

   $Q_{Treated} = 41{,}380$ gpd

3. Calculate Blending Ratio

   The blending ratio is obtained by dividing the treated flow rate by the total daily flow rate = $\frac{41{,}380}{100{,}000}$ Blending Ratio = 0.414

4. Calculate anion ion exchanger flow rate in gallons per minute. Although the unit will treat 41,380 gallons each day, it will only operate 6 hours per day. Thus the flow rate while operating must be calculated:

$$\text{Unit Flow Rate } (gpm_u) = Q_{Treated} \times \frac{24 \text{ hours/day}}{\text{Daily Operating Time}} \times \frac{1 \text{ day}}{1440 \text{ minutes}}$$

$$= 41{,}380 \text{ gpd} \times \frac{24 \text{ hours}}{6 \text{ hours}} \times \frac{1 \text{ day}}{1440 \text{ minutes}}$$

   Ion Exchanger Flow Rate $(gpm_u) = 115$

SYSTEM OPERATING FLOW EXAMPLE

CALCULATION OF BLENDING RATIO AND ION EXCHANGER FLOW RATE
Known or Assumed Information:

Maximum daily flow	100,000 gallons/day
Maximum weekly flow	500,000 gallons/week
Maximum nitrate level	15 mg/l

1. Assume:

   The unit will be sized to treat the maximum daily flow of 100,000 gallons by routinely operating 6 hours per day, 5 days per week (presumes sufficient storage capacity for weekend demand).

   Produced water at 0.5 mg/l NO_3-N will be blended with untreated water at 15 mg/l NO_3-N to provide a finished water of 9 mg/l NO_3-N or less.

2. Calculate quantity of water which must be treated to produce 100,000 gpd of blended water with no more than 9 mg/l NO_3-N using the following general equation:

$$Q_{treated} = Q_{Total} - \left[Q_{Total} \times \frac{(\text{Final } NO_3 - \text{Treated } NO_3)}{(\text{Untreated } NO_3 - \text{Treated } NO_3)} \right]$$

   Therefore:

$$Q_{Treated} = 100{,}000 \text{ gpd} - \left[100{,}000 \text{ gpd} \times \frac{(9 \text{ mg/l} - 0.5 \text{ mg/l})}{(15 \text{ mg/l} - 0.5 \text{ mg/l})} \right]$$

   $Q_{Treated} = 41{,}380$ gpd

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4. Calculate anion ion exchanger flow rate in gallons per minute. Although the unit will treat 41,380 gallons each day, it will only operate 6 hours per day. Thus the flow rate while operating must be calculated:

   Unit Flow Rate (gpm_u) =

$$Q_{Treated} \times \frac{24 \text{ hours/day}}{\text{Daily Operating Time}} \times \frac{1 \text{ day}}{1440 \text{ minutes}}$$

$$= 41{,}380 \text{ gpd} \times \frac{24 \text{ hours}}{6 \text{ hours}} \times \frac{1 \text{ day}}{1440 \text{ minutes}}$$

   Ion Exchanger Flow Rate (gpm_u) = 115

WATER ANALYSIS DATA CONVERSION EXAMPLE

EXPRESSING ANION CONCENTRATIONS TO VARIOUS BASES AND CALCULATING TOTAL ANIONS

Note: See Appendix B for more detailed explanation of Equations used in these samples.

Given the following analysis:

Constituent*	Concentration (mg/l)	Expressed As
NO_3-N	15	Nitrate Nitrogen (NO_3-N)
SO_4	50	Sulfate ($SO_4^=$)
HCO_3	75	Bicarbonate (HCO_3^-)
Cl	25	Chloride (Cl^-)

* ionic charge deleted for clarity.

1. Express NO_3-N (nitrate as nitrogen) in terms of NO_3-NO_3 (nitrate as nitrate)

General Equation:

$$Conc_B = Conc_A \times \frac{\text{Equivalent Weight B}}{\text{Equivalent Weight A}}$$

Given the NO_3^- concentration expressed as nitrogen is known to be 15 mg/l. It is desired to express the concentration not in terms of nitrogen but as nitrate. Use the general equation above, Table 10 (equivalent weights) and the given water analysis as follows:

Let: $Conc_B$ = Conc of NO_3 as N (NO_3-N) (from chemical analysis) = 15 mg/l for this example
Equivalent weight B = Equivalent weight Nitrate* = 62.005
Equivalent weight A = Equivalent weight Nitrogen = 14.007
* From Table 10

Therefore, to change the concentration of nitrate expressed as nitrogen to nitrate (as nitrate) the general equation beomes:

$$\text{mg/l } (NO_3\text{-}NO_3) = \text{mg/l } (NO_3\text{-N}) \times \frac{\text{Equivalent weight } NO_3}{\text{Equivalent weight N}}$$

$$\text{mg/l } (NO_3\text{-}NO_3) = \frac{15 \text{ mg}}{} \times \frac{62.005}{14.007}$$

$$\text{mg/l } (NO_3\text{-}NO_3) = 66.4$$

2. Calculate total anions

Total anion concentration, used in design of the resin bed, is determined by adding up the individual anion concentrations, expressed to a common base.

Anion*	Concentration mg/l	Milliequivalent weight (mg/meq)	Concentration meq/**
NO_3-N	15	14.007 $\frac{mg}{meq}$	1.07
SO_4	50	48.031	1.04
HCO_3	75	61.017	1.23
Cl	25	35.453	0.71
Total Anions			4.05 meq/l

* Ionic charge deleted for clarity
** See Appendix B for a detailed explanation of computation

3. Calculate ratio of sulfate and nitrate to total anions. This calculation is made using the general equation below. The concentration of all constituents used in the equations must be expressed to the same base, such as milliequivalents per liter.

$$\text{Ratio (\%)} = \frac{\text{Single Anion Concentration}}{\text{Total Anion Concentration}} \times 100$$

Using the information from Step 3.

$$\text{Sulfate Ratio \%} = \frac{\text{Sulfate Conc as meq/l}}{\text{Total Anion Conc as meq/l}} \times 100\%$$

$$= \frac{1.04}{4.05} \times 100\% = 26\%$$

$$\text{Nitrate Ratio \%} = \frac{\text{Nitrate Conc as meq/l}}{\text{Total Anion Conc as meq/l}}$$

$$\text{Nitrate Ratio \%} = \frac{1.07}{4.05} \times 100\% = 26.4\%$$

4. Daily nitrates to be removed

The total quantity of nitrates to be removed daily by the exchanger depends upon the initial concentrations of nitrate in the raw water, the concentration in the effluent and the total volume of water treated. The general equation below describes the relationship:

WATER ANALYSIS DATA CONVERSION EXAMPLE
(Continued)

Nitrate Removed (meq) = Initial Conc (meq/l) - final Conc (meq/l) x Daily Volume Treated in Liters

This equation can be written so that the daily volume treated can be entered in the equation in gallons:

Nitrate Removed (meq) = Initial Conc (meq/l) - final Conc (meq/l) x gallons treated x 3.785 $\frac{\text{liters}}{\text{gallon}}$

For our example:

Nitrate Removed = (1.07 meq/l - 0.04 meq/l x 41,380 gpd x 3.785 $\frac{\text{liters}}{\text{gallon}}$ = 161,996 meq per day

If the system is going to operate with only one regeneration cycle per day, the nitrate to be removed per cycle is also 161,996 meq.

Determining Resin Capacity, Bed Dimensions and Regenerant Requirements

o Resin Capacity

Resin capacity determines the amount of resin needed in the ion exchanger and is calculated from pilot test data and/or data provided in the manufacturer's manual. For purposes of illustration, resin capacity in this example is based on the Diamond Shamrock A-104 strongly basic resin. Characterisitics and manufacturer's recommended practices are shown in Table 12 and are given in the A-104 resin guidebook.(14)

This resin can be used for nitrate removal and is described as a chloride cycle resin. This means that it is regenerated by a salt (NaCl) brine solution in an operation much like that of a typical water softener.

The operating capacity of A-104 resin for nitrate removal is quite dependent on the sulfate, nitrate and total anion concentrations. These were calculated in the example on the previous page.

Known, Assumed or Previously Calculated Data:

- design flow rate through exchanger
- influent nitrate and sulfate, as meq/l
- total anions (TA) as meq/l
- suggested operating conditions for resin (Table 12)

Data yet to be Determined:

- Corrected resin capacity.

TABLE 12

SUGGESTED DESIGN PARAMETERS FOR A-104 RESIN[14]

Minimum bed depth	30 inches
Backwash flow rate	2 to 3 gpm/sq.ft.
Regenerant concentration	15 to 18 lbs sodium chloride (NaCl)/ft^3 resin
Regenerant concentration	10 to 12 percent NaCl (by weight)
Regenerant temperature	Up to 120°F (49°C)
Regenerant flow rate	0.5 gpm/cu.ft.
Rinse flow rate	2 gpm/cu.ft.
Rinse volume	50 to 70 gals./cu.ft.
Service flow rate	Up to 5 gpm/cu.ft.
pH limitation	None
Operating temperatures	Salt form - up to 185°F (85°C)

Using the known data and the manufacturer's product information, the corrected resin capacity can be determined.

First, determine the raw, or uncorrected resin capacity from the manufacturer's data. This is generally available from a graph such as Figure 13. This capacity must be adjusted downward to reflect the presence of sulfate in the water supply. Since sulfate anions will be exchanged before nitrate, the final resin capacity used for design must be reduced accordingly. This is accomplished with the aid of another graph such as the one reproduced as Figure 14.

o Bed Dimensions

Once the adjusted resin capacity is determined for the specific water to be treated, the required volume of ion exchange resin (bed volume) can be calculated. Bed volume is determined by dividing the amount of nitrate that must be removed each cycle by the adjusted resin capacity. (See Step 2 of the exchanger sizing example.) Using this bed volume, the remaining bed dimensions are determined by using the manufacturer's minimum depth and adjusting first the surface area to get a standard size containment vessel and the height of the vessel to allow for bed expansion during backwashing (Steps 3 and 4 of sizing example and Figure 15).

o Regenerant Requirements

Once the bed volume and dimensions are available, the regeneration system requirements can be calculated using these and additional information provided by the manufacturer. Required manufacturer's information may include:

Backwash flow rate
Regenerant dosage
Regenerant concentration
Regenerant temperature
Regenerant flow rate

The regeneration system design must determine:

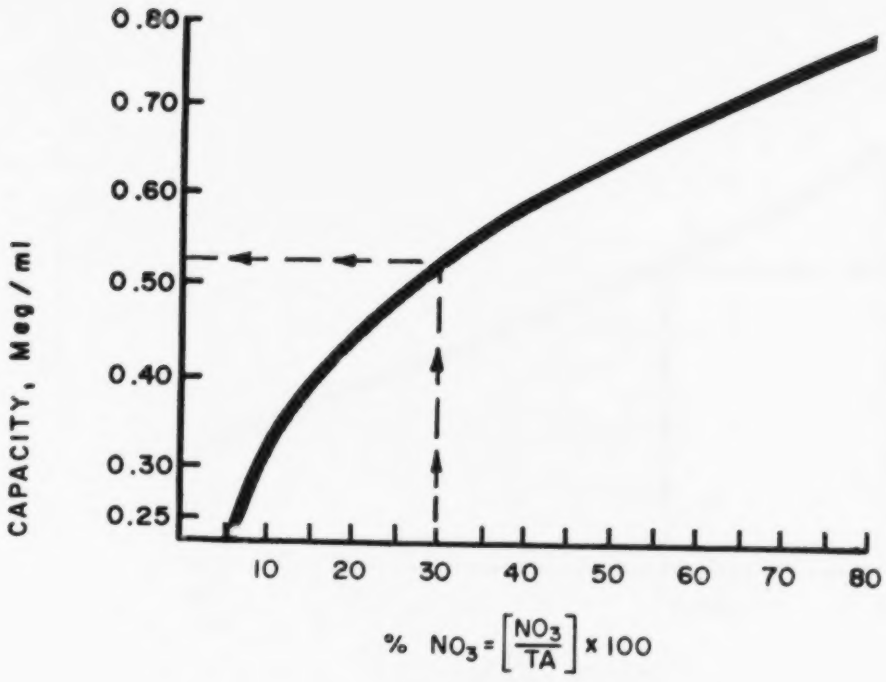


Figure 13. NO_3/TA vs. Unadjusted Resin Capacity for A-104 Resin

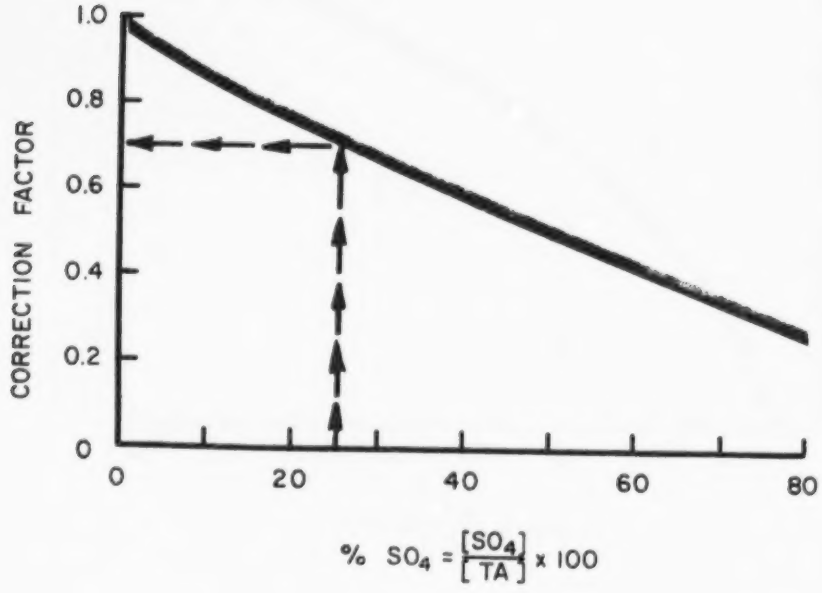
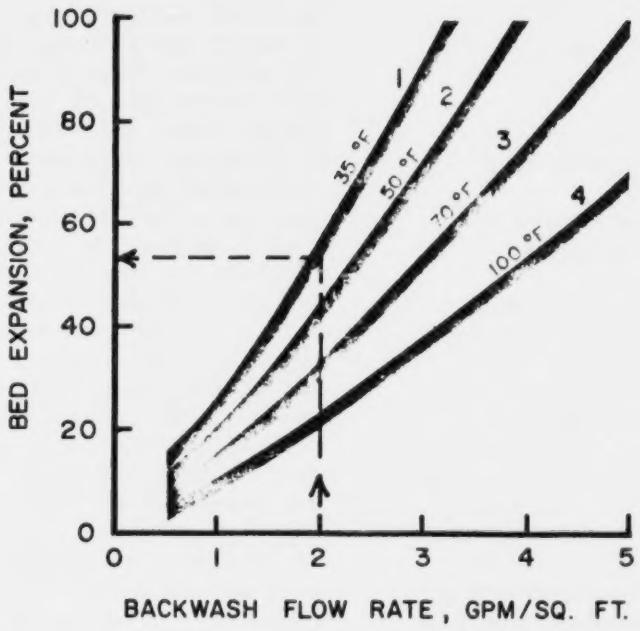


Figure 14. Sulfate Correction Curve for A-104 Resin



NOTE:

Curve 1	-	35°F
Curve 2	-	50°F
Curve 3	-	70°F
Curve 4	-	100°F

Figure 15. Bed Expansion Curve for A-104 Resin

1. the amount of salt used each regeneration cycle,

2. the volume of brine used each cycle,

3. the total volume of the brine storage tank, and

4. the time required for the regeneration process.

The amount of salt required is based on the volume of the resin in use and the manufacturer's information which specifies pounds of salt required for regeneration per cubic foot of resin. Knowing the total pounds of salt used and the required concentrations of the salt brine regenerant as specified by the manufacturer, the corresponding volume of brine required for each regeneration can be calculated (see Steps 5 and 6 of the sizing example). Holding tanks generally are designed to provide sufficient volume for 2-3 regeneration cycles. Finally, the time required for regeneration can be determined by dividing the volume of brine required per regeneration cycle by the regeneration flow rate specified by the manufacturer.

Other Design and Purchase Considerations

Other factors effect the design, purchase and operation of the system. These include:

- Process control and monitoring
- Equipment redundancy
- Salt handling and storage
- Materials of construction
- Spent regenerant disposal

- PROCESS CONTROL AND MONITORING

As noted earlier, the operation of small ion exchange systems for nitrate removal is quite similar to that of the more common water softener. Thus, nitrate ion exchangers can be controlled by flow totalizers just as water softeners are. A flow totalizer is a device included in an accurate water meter/controller that can be set to trigger regeneration after a given quantity of water has passed through the unit. Regeneration, backwashing and flushing then proceed automatically, controlled by a timer activated switch that operates a motorized valve. The technology of this control system is well established and highly reliable. However, because of the potential dangers associated with a failure of the nitrate removal system, additional safeguards are warranted to ensure the exchanger is not operated to resin exchange capacity exhaustion:

1. The process stream flow totalizer should have a warning light and/or bell to alert the operator when regeneration is automatically initiated. If possible, the operator should be present during the regeneration cycle, observing that regeneration is proceeding correctly.

2. Salt brine feed during regeneration should be visually observed by the operator and quantities checked during and after regeneration.

3. Regenerant flow should be metered to ensure that the

SIZING THE ION EXCHANGE UNIT EXAMPLE

1. Determine the uncorrected volume of exchange resin required:

   a. Using the nitrate to total anion ratio (%) of 30 from the previous example, use Figure 13 to determine the uncorrected resin capacity of 0.51 meq NO_3/ml resin.

   This is <u>not</u> the final capacity; it must be adjusted for sulfate concentration as shown below:

   b. Using the sulfate ratio (%) of 25 from the previous example and Figure 14, determine the resin capacity correction factor of 0.7.

   c. Multiply the uncorrected resin capacity by the correction factor to determine the corrected or adjusted resin capacity = 0.7 x 0.51 = 0.357 meq/ml.

   d. Convert these units from meq/ml to meq/ft^3:

   $$0.357 \text{ meq/ml} \times 3785 \text{ ml/gal} \times 7.48 \text{ gal/ft}^3$$

   $$= 10{,}107 \text{ meq/ft}^3$$

2. Using milliequivalents nitrate to be removed each cycle and the adjusted resin capacity per cubic foot, determine the bed volume (BV) of resin required:

   $$BV = \frac{161{,}996 \text{ meq}}{10{,}107 \text{ meq/ft}^3} = 16.1 \text{ ft}^3$$

3. Check to make certain that the manufacturer's maximum service flow rate (5 gal/ft^3 from Table 12) is not exceeded:

   $$\text{Service Flow Rate} = \frac{\text{Ion Exchange Unit Flow Rate}}{\text{Ion Exchange Unit Volume}}$$

   $$= \frac{115 \text{ gpm}}{16.1 \text{ ft}^3} = 7.1 \text{ gpm/ft}^3$$

   Since the maximum allowable flow rate would be exceeded, either the exchanger operating time per cycle would have to be increased to reduce the service flow rate, or the bed volume must be adjusted. Both methods are demonstrated below:

   a. The adjusted operating time can be determined by using the following equation:

$$\frac{\text{Adjusted Service Time}}{\text{cycle}} = \frac{\text{Design Time}}{\text{cycle}} \times \frac{\text{Calculated Service Flow}}{\text{Max. Allowed Service Flow}}$$

$$= \frac{6 \text{ hours}}{\text{cycle}} \times \frac{7.1 \text{ gpm/ft}^3}{5.0 \text{ gpm/ft}^3}$$

$$= 8.5 \text{ hours/cycle}$$

The adjusted flow rate during this cycle would be

$$\frac{\frac{41,380 \text{ gal}}{\text{cycle}}}{8.5 \text{ hours/cycle} \times \frac{60 \text{ min.}}{\text{hour}}} = 81 \text{ gpm}$$

b. As an alternative, the initial flow rate can be retained, but the ion exchange bed volume can be adjusted to make sure the service flow rate does not exceed the manufacturer's recommendations. Bed volume can be adjusted as follows:

$$\text{Adjusted BV} = \text{Design BV} \times \frac{\text{Calculated Unit Service Flow Rate}}{\text{Max. Allowable Unit Service Flow Rate}}$$

$$\text{Adjusted BV} = 16.2 \text{ ft}^3 \times \frac{7.1 \text{ gpm/ft}^2}{5 \text{ gpm/ft}^2}$$

$$\text{Adjusted BV} = \underline{23 \text{ ft}^3}$$

For the purpose of this example, it will be assumed that it is more desirable to be able to complete the treatment and regeneration cycle during the normal 8 hour shift than it is to save the capital costs by minimizing the size of the resin exchange bed. BV is therefore taken to be $\underline{23 \text{ ft}^3}$.

4. Determine Bed Dimensions

Minimum bed depth (Table 12) is 30 inches or 2.5 feet. Since Volume = Area x Depth, Area = $\frac{\text{Volume}}{\text{Depth}}$. Using a minimum depth of 2.5 ft. the area can be calculated as $\frac{23 \text{ ft}^3}{2.5 \text{ ft}} = 9.2 \text{ ft}^2$

For a circular vessel, Area = $\frac{\text{Pi (Diameter)}^2}{4}$

Therefore: Diameter = $\sqrt{\frac{4 \times \text{Area}}{\text{Pi}}}$

For this example:

$$\text{Diameter} = \sqrt{\frac{4 \times 9.2 \text{ ft}^2}{3.14}} = 3.42 \text{ ft}$$

A reactor vessel of circular cross section would have a diameter of 3.42 feet and most likely, the closest premanufactured size would be 3.25 feet with a corresponding area of 9.62 ft^2. The bed depth would then be adjusted so the required volume of 23 ft^3 would be available:

Volume = Area x Depth, therefore $\text{Depth} = \frac{\text{Volume}}{\text{Area}}$

$$\text{Depth} = \frac{23 \text{ ft}^3}{9.62 \text{ ft}^2}$$

$$= 2.4 \text{ ft}$$

Adjusting for Expansion During Backwash

The bed depth must be adjusted to allow sufficient room for bed expansion during the backwash cycle. This design adjustment is accomplished with the aid of Figure 15 and manufacturer's data from Table 12. If we assume that the backwash flow rate is 2 gpm/ft^2 (Table 12) and that under the worst temperature condition, the backwash water temperature will be 35°F, the percent bed expansion of 56% is determined from the graph in Figure 15. Then the following equation can be used to determine the final vessel depth:

Adjusted bed depth equals unadjusted bed depth + unadjusted depth x $\frac{\%\text{ expansion}}{100}$

For this Example:

$$\text{Adjusted bed depth} = 2.4 \text{ ft} + 2.4 \frac{(56)}{100} = 3.74 \text{ ft}$$

5. Regeneration System:

Salt required per regeneration cycle: From Table 12, Regeneration dosage = 15 to 18 pounds sodium chloride (NaCl) per cubic foot of resin. For this example, 18 lb/ft^3 is assumed.

$$\frac{\text{Salt required}}{\text{cycle}} = \frac{18 \text{ lbs}}{\text{ft}^3} \times 23 \text{ ft}^3 = 414 \text{ lbs/cycle}$$

For this example:

$$\text{Diameter} = \sqrt{\frac{4 \times 9.2 \text{ ft}^2}{3.14}} = 3.42 \text{ ft}$$

A reactor vessel of circular cross section would have a diameter of 3.42 feet and most likely, the closest premanufactured size would be 3.25 feet with a corresponding area of 9.62 ft^2. The bed depth would then be adjusted so the required volume of 23 ft^3 would be available:

$$\text{Volume} = \text{Area} \times \text{Depth, therefore Depth} = \frac{\text{Volume}}{\text{Area}}$$

$$\text{Depth} = \frac{23 \text{ ft}^3}{9.62 \text{ ft}^2}$$

$$= 2.4 \text{ ft}$$

Adjusting for Expansion During Backwash

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$$\frac{\text{Salt required}}{\text{cycle}} = \frac{18 \text{ lbs}}{\text{ft}^3} \times 23 \text{ ft}^3 = 414 \text{ lbs/cycle}$$

6. Volume of brine required per regeneration cycle:

$$\text{Salt concentration \%} = \frac{\text{Wt. of Salt}}{\text{Total Weight Brine}} \times 100$$

$$10\% \text{ (from Table 12)} = \frac{414 \text{ lb}}{\text{Total Weight Brine}} \times 100$$

$$\text{Total Weight Brine} = 4140 \text{ lbs.}$$

$$\begin{aligned}\text{Weight of Water} &= \text{Total Wt.} - \text{Wt. of Salt} \\ &= 4140 \text{ lbs.} - 414 \text{ lb.} \\ &= 3726 \text{ lbs.}\end{aligned}$$

$$\text{Volume of Water } (ft^3) = \frac{\text{Wt. Water (lbs)}}{\text{Density } (lb/ft^3)}$$

$$= \frac{3726 \text{ lbs}}{62.4 \text{ lb/ft}^3}$$

$$= 59.71 \text{ ft}^3$$

$$\text{Volume of Salt } (ft^3) = \frac{\text{Wt. Salt}}{\text{Density}} = \frac{414}{(62.4) \times (2.165)}$$

$$= 3.06 \text{ ft}^3$$

$$\begin{aligned}\text{Total Volume} &= \text{Water \& Salt} = 59.71 + 3.06 \\ &= 62.78 \ (ft^3)\end{aligned}$$

$$\text{Total Volume (gallon)} = 62.78 \text{ ft}^3 \times \frac{7.48 \text{ gallon}}{(ft^3)} = 470 \text{ gallons}$$

This brine tank should contain sufficient volume for 3-4 regenerations. If 3 regenerations used, the total brine tank volume must be 470 gal/cycle x 3 = 1410 gal.

7. Regeneration Cycle Operating Time

$$\text{Regeneration time} = \frac{\text{Volume of Brine}}{\text{Flow Rate of Brine}}$$

$$\begin{aligned}\text{Flow rate of brine} &= 0.5 \text{ gpm/ft}^3 \text{ resin (from Table 12)} \\ &= 0.5 \text{ gpm/ft}^3 \times 23 \text{ ft}^3 \\ &= 11.5 \text{ gpm}\end{aligned}$$

$$\text{Regeneration time} = \frac{470 \text{ gal}}{11.5 \frac{\text{gal}}{\text{min}}} = 41 \text{ minutes}$$

brine actually passes through the bed in the required quantities. A sight glass or break in the drain line should be provided so that waste flows can be visually observed.

4. Protective instrumentation, as illustrated in Figures 16a and 16b, should be incorporated in the system.

5. Spot checking of product water for nitrate removal, using a calibrated field test kit, should be routinely performed by the plant operator (see Section VI, Operation and Maintenance).

   All systems should also consider using a continuous on-line nitrate analyzer which will actuate alarms and initiate automatic system shutdown in case of nitrate breakthrough. Reference 15 describes an analyzer/ controller in use by the Garden City Park Water District, of New York (Long Island).

o Equipment Redundancy

The need for backup equipment is determined largely by state and local regulatory requirements and the consequences of main system shutdown for repair. If the water supply is quite high in nitrate and no backup water supply or large reserve is available, two fully equipped parallel systems are justified. At the opposite extreme, a very small system with raw water quality near the standard (i.e., Curryville, PA, described in Section VII) can get by with a single system.

Typically, a system could have two parallel exchanger vessels served by a single regeneration/ backwash system.

o Salt Handling and Storage

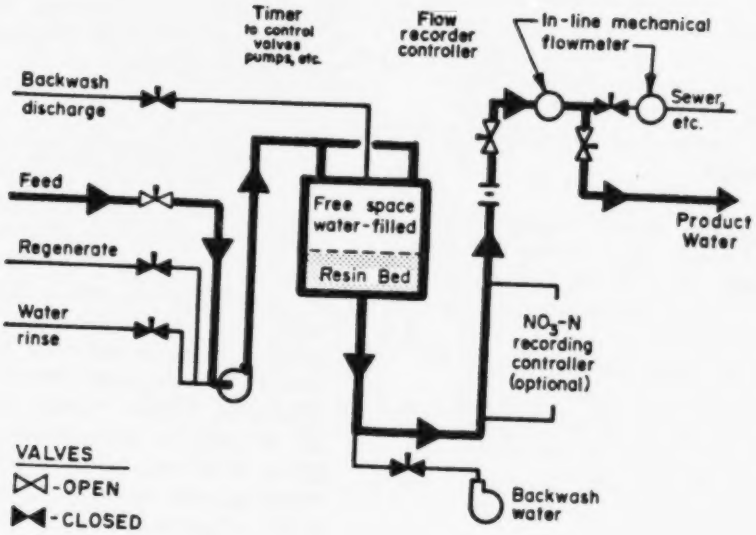
Regeneration for nitrate removal requires a considerable amount of rock salt (NaCl) which must be stored in a cool, dry place. Salt is corrosive but is otherwise nontoxic and can be readily handled. Storage and brine solution tanks should be constructed of highly corrosion resistant materials and operators should wear gloves when handling the salt simply to avoid skin irritation.

o Materials of Construction

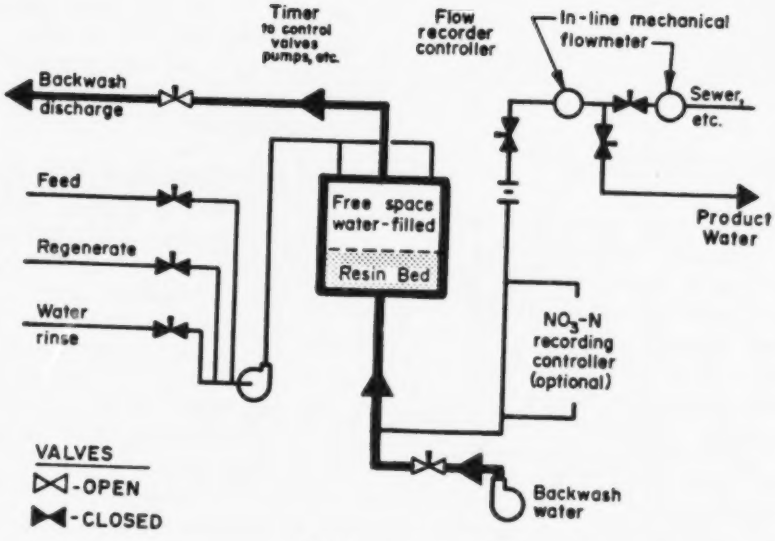
Although the process water stream will usually be only slightly corrosive, the regenerant stream, at 10 to 12 percent salt content, will be highly corrosive (similar to sea water). Use of more expensive but corrosion resistant materials will be very cost effective over the life of the system. For example:

- High strength PVC (polyvinyl chloride) piping should be used, where system pressures permit, as this material is corrosion free. Fittings should be of the same material or better.

- Plastic epoxy lining or galvanizing for vessels is suggested. The brine tank, where the rock salt and water are mixed, should be galvanized and lined, or protected by a plastic liner. Smaller

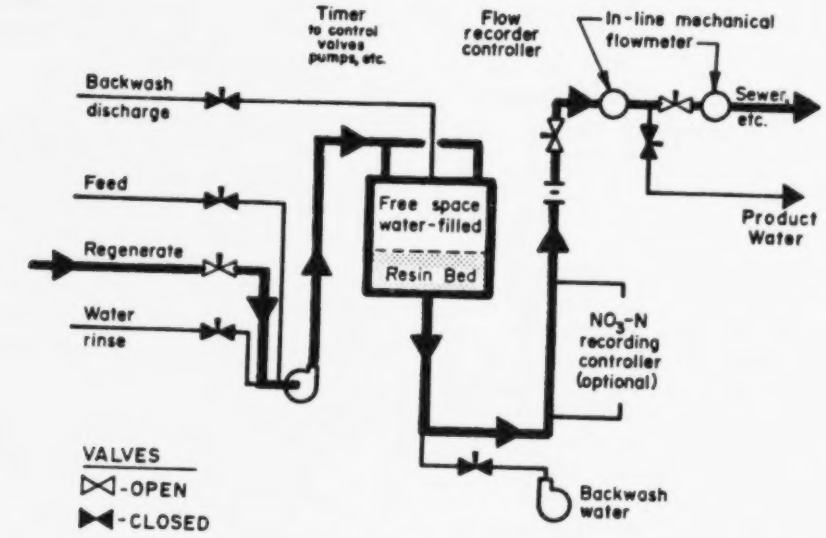


Normal Operation Cycle

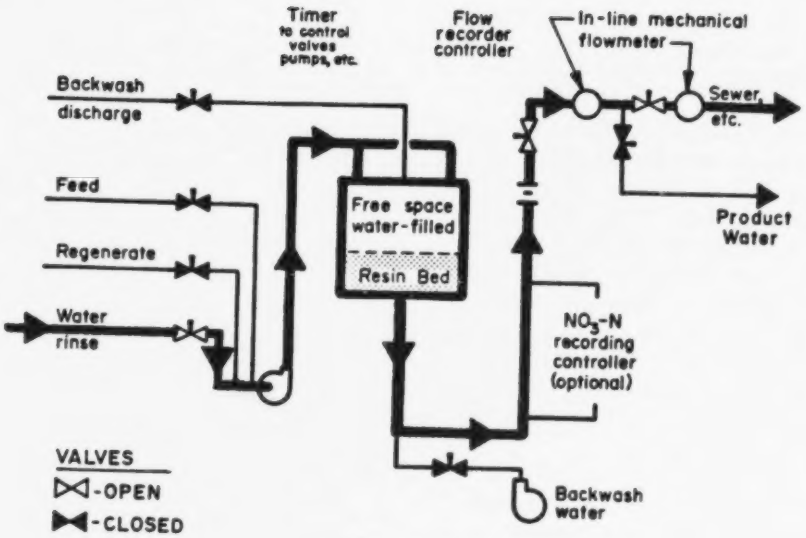


Backwash Cycle

Figure 16a. Protective Monitors



Regeneration Cycle



Rinse Cycle

Figure 16b. Protective Monitors

systems may be able to use all plastic or fiberglass brine tanks.

- Meters and other instruments should be designed and warranted for corrosive service.

- Spent Regenerant Disposal

Ion exchange systems do not provide ultimate disposal of the nitrate removed from the process water stream. They simply move nitrate, sulfate and a substantial amount of spent brine to the waste stream. In the process design example, the hypothetical 100,000 gpd (after blending) system would use about 410 pounds of salt every day, and generate a waste stream of approximately 400 gallons per day having a total dissolved solids concentration exceeding 12,000 mg/l.

There are currently few practical means of removing the water or otherwise treating this waste stream. Thus, disposal alternatives are generally limited to the following:

- Direct discharge to a stream or other surface water--the spent brine can be diluted in the stream flow so that final total dissolved solids (TDS) and nitrate levels are acceptable. This may have an adverse effect on a fresh water stream. A discharge permit from the state water pollution control authority may be required.

- Direct discharge to a sewer system--again, the spent brine must be diluted so that the resultant salt and nitrate levels do not interfere with the waste treatment system or violate treatment facility discharge permit requirements.

- Evaporation in a lined pond--it may be possible in dry climates to evaporate the water from the salt in a simple holding pond located on-site or nearby. The dried salt can be periodically removed and disposed in an approved landfill.

- Truck spent brine to an acceptable off-site disposal site.

- Ocean discharge for coastal facilities.

Generally, septic tank disposal or disposal in unlined ponds will be unacceptable as it may lead to salt and nitrate pollution of adjacent ground waters.

V. COST ESTIMATING PROCEDURES AND FUNDING SOURCES

This section provides a summary of the kinds of costs that are likely to be encountered in any treatment facility construction project and outlines a procedure to estimate costs associated with treatment for nitrate removal. It also summarizes some estimated construction and operating cost projections which have been made for ion exchange nitrate removal systems, explains how to update costs, and provides an overview of potential funding sources for small water utilities.

Costs depend largely on site-specific conditions some of which may change over time. The cost estimates in this report were based on assumptions made when the cost curves were developed (1976-78). In this regard, other projects are currently in progress to refine and improve the accuracy of cost estimating procedures. As these projects are completed they should be consulted for more accurate cost estimation procedures.

The total cost estimate for a water treatment facility is generally the sum of the costs associated with two major categories: (1) construction costs and (2) operation and maintenance costs. Each of these major cost categories is composed of individual costs for a number of components. To arrive at a total cost estimate for a given facility, the component costs are evaluated, adjusted as necessary for site-specific considerations and inflation, then summed. Costs can be expressed many ways: annual cost and cost per thousand gallons treated are two of the most common. The latter can be used directly to estimate the effect the project will have on the individual consumer's water bill. However, cost curves are generally most useful for comparing relative costs of the treatment alternatives and for approximating the general cost level to be expected for a proposed treatment system.

CONSTRUCTION COSTS

Introduction

Whenever treatment costs are determined, whether from a published report or a vendor's estimate, it is extremely important to establish exactly what components and processes the cost estimate includes. Different cost estimates based on different basic assumptions (such as water quality) and different components (such as housing) have in the past resulted in many misunderstandings. In addition, if the costs are taken from a report, it is important to be sure they apply to the size category of your system. Once this has been ensured, cost comparisons between alternatives can be made using the process outlined above. To illustrate this procedure, the cost information developed by the EPA Municipal Environmental Research Laboratory [presented in a 4-volume report titled: Estimating Water Treatment Costs (EPA-600/2-79-162)].(1) can be used. This report presents cost curves for 99 unit processes useful for removing contaminants covered by the NIPDWR.

The construction cost curves in Reference 1 were developed by using equipment cost data supplied by manufacturers, cost data from actual plant construction, published data, and estimating techniques from Richardson Engineering Services Process Plant Construction Estimating Standards, Mean's Building Construction Cost Data, and the Dodge Guide for Estimating Public Works Construction Costs. The construction cost curves were then checked and verified by an engineering consulting firm.

Although the cost data in Reference 1 may be somewhat outdated, the method used to generate those costs provides an outline of the things you should consider when developing your own estimates. For example:

- Excavation and Site Work

  This category includes work related only to the applicable process and does not include any general sitework such as sidewalks, roads, driveways, or landscaping which should be itemized separately.

- Manufactured Equipment

  This category includes estimated purchase costs of pumps, drives, process equipment, specific purpose controls, and other items that are factory made and sold with equipment.

- Concrete

  This category includes the delivered cost of ready-mix concrete and concrete-forming materials.

- Steel

  This category includes reinforcing steel for concrete and miscellaneous steel not included within the manufactured equipment category

- Labor

  The labor associated with installing manufactured equipment, and piping and valves, constructing concrete forms, and placing concrete and reinforcing steel are included in this category

- Pipe and Valves

  Cast iron pipe, steel pipe, valves, and fittings have been combined into a single category. The purchase price of pipe, valves, fittings, and associated support devices are included within this category.

- Electrical Equipment and Instrumentation

  The cost of process electrical equipment, wiring, and general instrumentation associated with the process equipment is included in this category.

- Housing

  In lieu of segregating building costs into several components, this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting,

normal convenience outlets, and the slab and foundation.

To the subtotal for construction costs is normally added 15 percent for contingencies.

The total construction cost is obtained by adding in the following items:

Special sitework
General contractor overhead and profit
Engineering
Interest
Land
Legal, fiscal, administrative services

These are not directly applicable to the costs for specific processes. Rather, when using these cost curves, they should be added in after process costs have been estimated. Typically, these will average 30 to 35 percent of the total construction cost. The cost curves of Reference 1 do not include these items; they must be added on to arrive at a total cost estimate.

The costs from Reference 1 are based on October 1978 dollars and can be updated by using the Engineering News Record (ENR) Construction Cost Index (CCI), or Building Cost Index (BCI).

The following formula can be used to update construction costs:

$$\text{Updated Cost} = \text{Cost from Curve} \times \frac{\text{(Current ENR Construction Cost Index [CCI])}}{\text{(ENR CCI When Costs were Determined)}}$$

The cost curves used in this document from Reference 1 are based on October 1978 costs when the ENR* CCI was 265.38.

As of June 1982, the ENR CCI was 352.92. Thus to update the Reference 1 cost estimates, they must be multiplied by the ratio of 352.92/265.38 which equals 1.33.

Note that this is the average of the 20 city construction cost index--there is wide variation between individual cities and regions of the U.S. For example, the August 1981 index varied from a low of 274 to a high of 360 among the 20 cities, about a 31 percent difference. As a result, updated cost figures using this adjustment may tend to overestimate or underestimate costs, depending on construction costs in the locality of interest. More sophisticated cost estimating techniques are available; they are described in Reference 1.

Reference 1 Construction Cost Basis and Assumptions

Reference 1 costs were developed for treatment of a water supply with the following anion content: Nitrate-nitrogen = 22.2 mg/l, sulfate = 80 mg/l, other anions = 120 mg/l. The work assumed a strongly basic anion exchange resin operated with sodium chloride regenerant. Note that other water supplies with different quality may cause the resin to have significantly different exchange capacities,

* Engineering News Record, (ENR), is a McGraw-Hill Publication which summarizes periodically updated construction cost indices weekly.

depending generally on the nitrate-to-sulfate ratio.

Regenerant required was assumed to be 15 pounds salt/cu.ft. of resin. A total regeneration time of 54 minutes was assumed. Backwash required 10 minutes, the brine contact and slow rinse 24 minutes and the fast rinse an additional 20 minutes.

Construction costs were developed for pressure anion exchange systems using the design basis in Table 13. Contact vessels were fabricated steel, with a 100-psi working pressure and a baked phenolic lining. A 6-foot bed depth was utilized, and tanks were sized for up to 80 percent resin expansion during backwash. A gravel layer between the resin and the underdrains was not assumed.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures, constructed with the top foot above ground level. A salt storage capacity of 4 days was provided. A saturated 26 percent brine is pumped from these storage basins to the contact vessel using an eductor to dilute the brine to 10 percent concentration as it is being transferred.

Brine, transfer, and backwash pumping facilities are included in the cost estimate. Costs for spent regenerant disposal are not included as they are highly site-specific. They must not be ignored, however, if true cost estimates are to be prepared. Construction costs are presented in Table 14 and in Figure 17.

Annualizing Construction Costs

To determine the true total yearly cost of owning, maintaining, and operating a nitrate removal system, all costs must be stated on an annualized basis. As shown later herein, O&M costs are normally stated on this basis. Capital costs can be annualized as a series of equal payments needed to recover the initial expenditure over the life of the project, plus interest costs.

The size of the annual payment needed to recover the initial capital cost can be determined by multiplying the lump sum amount times a capital recovery factor (CRF).

Annualized Construction Cost = Construction Cost x CRF

The CRF is a function of the interest rate "i" (cost of money) and the life of the system in years (n)[16]:

$$CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1}$$

Many economics handbooks provide tables of CRF values corresponding to various combinations of interest and financing period. Table 15 is an abbreviated example of this type of table, from Reference 16. The cost example beginning on page V-12 shows how this can be used to find the annual cost of a proposed system's capital cost based on the expected financing term and interest cost.

TABLE 13

CONCEPTUAL DESIGN FOR PRESSURE ION EXCHANGE NITRATE REMOVAL*

Treatment Capacity (gpd)	Number of Contactors	Diameter of Contactors (ft.)	Housing sq.ft.
70,000	2	2	132
270,000	2	4	210
425,000	2	5	255

TABLE 14

CONSTRUCTION COST FOR PRESSURE ION EXCHANGE NITRATE REMOVAL*

	Plant Capacity (gpd)		
Cost Category	70,000	270,000	425,000
Excavation and Sitework	50	110	140
Manufactured Equipment:			
Equipment	11,860	16,500	19,090
Media	5,460	21,860	34,160
Concrete	280	490	550
Steel	420	680	950
Labor	4,770	5,990	6,880
Pipe and Valves	9,650	12,440	13,600
Electrical and Instrumentation	18,390	21,460	23,070
Housing	7,600	8,900	9,800
Subtotal	58,480	88,430	108,240
Miscellaneous and Contingency	8,770	13,260	16,240
Total	$67,250	$101,690	$124,480
ENR CCI October 1978 = 265.38			

* Reference 1.

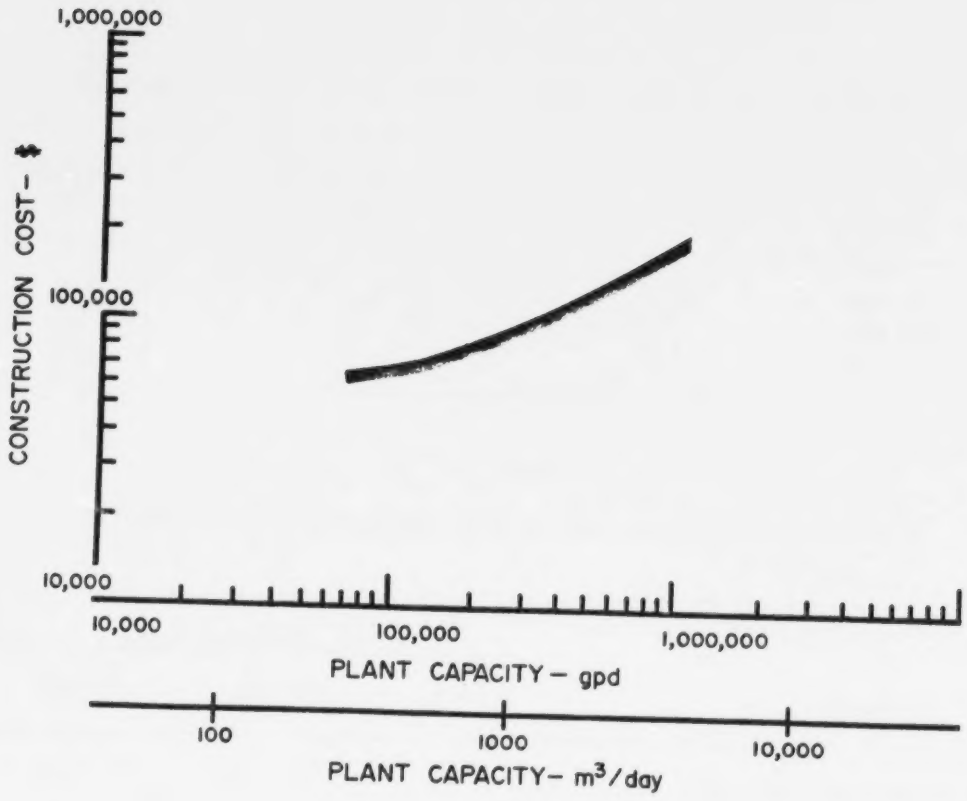


Figure 17. Construction Cost Curves for Ion Exchange Nitrate Removal

TABLE 15

CAPITAL RECOVERY FACTORS FOR SOME COMBINATIONS OF INTEREST (i) AND FINANCING PERIOD (n)

n Years	6%	7%	8%	9%	10%	12%
5	0.237396	0 243891	0 240456	0 257092	0 263797	0 277410
10	0.135868	0.142378	0 149029	0.155820	0.162745	0.176984
15	0.102963	0 109795	0.116830	0.124059	0.131474	0.146824
20	0.087185	0.094393	0.101852	0.109546	0.117460	0.133879
25	0.078227	0.085811	0.093679	0.101806	0.110168	0.127500

OPERATION AND MAINTENANCE COSTS

To obtain a total operation and maintenance (O&M) cost, the individual costs for energy (process and building heating), maintenance material, and labor must be determined and summed.

Total operation and maintenance costs from a reference document or previous contractor's estimate can be updated and adjusted to local conditions by updating and adjusting the operation and maintenance cost components: energy, labor, and maintenance material. Energy and labor requirements are generally provided in kilowatts per year and hours per year, respectively, and cost curves are developed by multiplying these requirements by the cost of power and labor respectively. To update such a curve, the cost per year is multiplied by the ratio of current energy or labor costs divided by the respective unit cost used to develop the original cost curve. For example, assume an available energy cost curve is based on an energy cost of $0.03 per kilowatt hour; if electricity now costs $0.05 per kilowatt hour the current annual energy cost for a given facility can be determined by multiplying the annual cost from the graph by the ratio of: $\frac{0.05}{0.03}$.

Likewise maintenance material costs are related to the Producer Price Index (PPI) for Finished Goods. To update this component, the PPI at the time the original cost estimates were made must be known. Then the new annual cost is determined by multiplying the cost from the graph by the ratio of the new PPI divided by the PPI at the time the graph was prepared. The technique is also demonstrated in the example (page V-12).

O&M COST BASIS AND ASSUMPTIONS

O&M costs were also estimated in Reference 1 and are included in this section. The basis and assumptions used are outlined below.

Electrical costs inclue backwash, rinse, and regenerant pumping, building heating, lighting and ventilation. Backwash pumping was based on a 10-minute wash at 3 gpm/sq.ft. Regenerant pumping was based on a rate of 6 gpm/sq.ft. of resin for 24 minutes, and fast-rinse pumping was based on a rate of 8 gpm/sq.ft. of resin for 20 minutes. All pumping was

assumed to be against a 25-foot total developed head. Feed water pumping requirements are not included.

Maintenance material costs for periodic repair and replacement of components were estimated based on 1 percent of the construction cost plus the cost of resin replacement. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity as a result of chemical fouling. An anion resin is typically replaced every 3 to 5 years; a 25 percent annual resin replacement was included to account for resin fouling and resin loss. Regenerant costs may be significant but are not included in the maintenance material costs provided. These must be included to determine total O&M cost.

Labor requirements are for operation and maintenance of ion exchange vessels and the pumping facilities. Hours were estimated based on filtration plants and filter pumping facilities of comparable size which generally require the same level of labor attention.

Labor requirements are also included for periodic media addition and replacement of the media every 4 years. No costs are included for spent brine disposal. These costs may be significant and are highly site-specific. They must be considered to determine total O&M costs.

Operation and maintenance curves are presented in Figure 18 and are summarized in Table 16.

Energy costs are based on $0.03 per kilowatt hour, labor costs are based on $10.00 per hour and maintenance material costs are based on a PPI of 199.7.

The above costs do not include an estimate of the costs associated with regeneration of the media. This cost is highly dependent upon system throughput and the sulfate and nitrate concentration of the raw water.

Figure 19 relates regeneration cost to sulfate and nitrate concentrations. One hundred percent efficiency of sulfate and nitrate removal is assumed. Salt cost is assumed to be 1.5 cents per pound. For other salt costs, multiply the regeneration costs from Figure 19 by the ratio of actual cost in cents divided by 1.5.

To use Figure 19, determine sulfate and nitrate concentration of the raw water. Enter the graph at the sulfate concentration and read the regenerant cost for the standard 33.3 mg/l NO_3-N concentration. Determine your cost using the following equation:

your cost = (cost from Figure 19 for 33.3 mg/l NO_3-N
times (the number of thousand gallons treated)
times (the ratio of your nitrate-nitrogen concentration in mg/l divided by 33.3)
times (the ratio of your salt cost divided by 1.5 cents per pound)

OR

your cost = (Figure 19 cost) x

$$\frac{\text{(gallons treated)}}{} \frac{\left(\frac{\text{your } NO_3\text{-N conc.}}{}\right)}{\left(\frac{33.3 \text{ mg/l } NO_3\text{-N}}{}\right)} \frac{\text{(your salt cost)}}{\left(\frac{1.5¢/\text{lb.}}{}\right)}$$

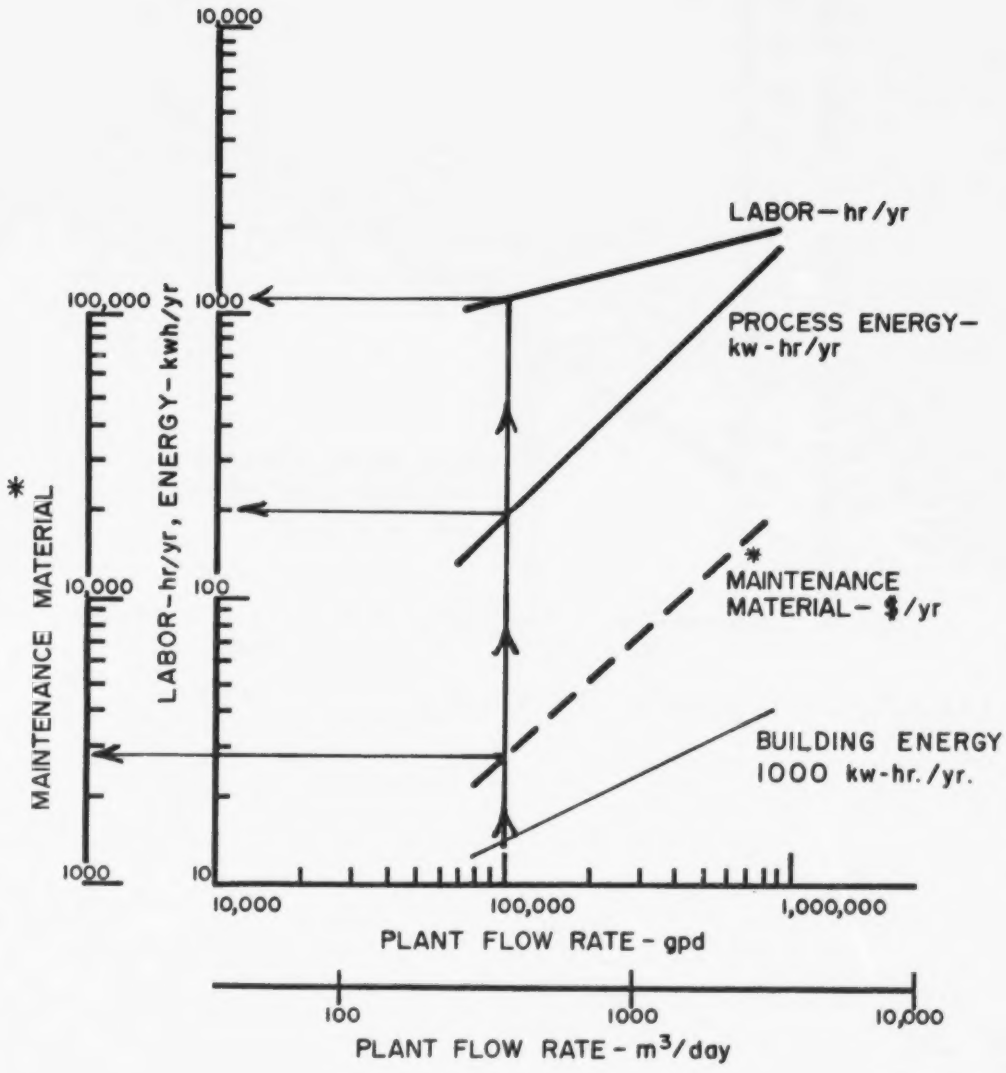


Figure 18. Operation and Maintenance Costs for Ion Exchange Nitrate Removal

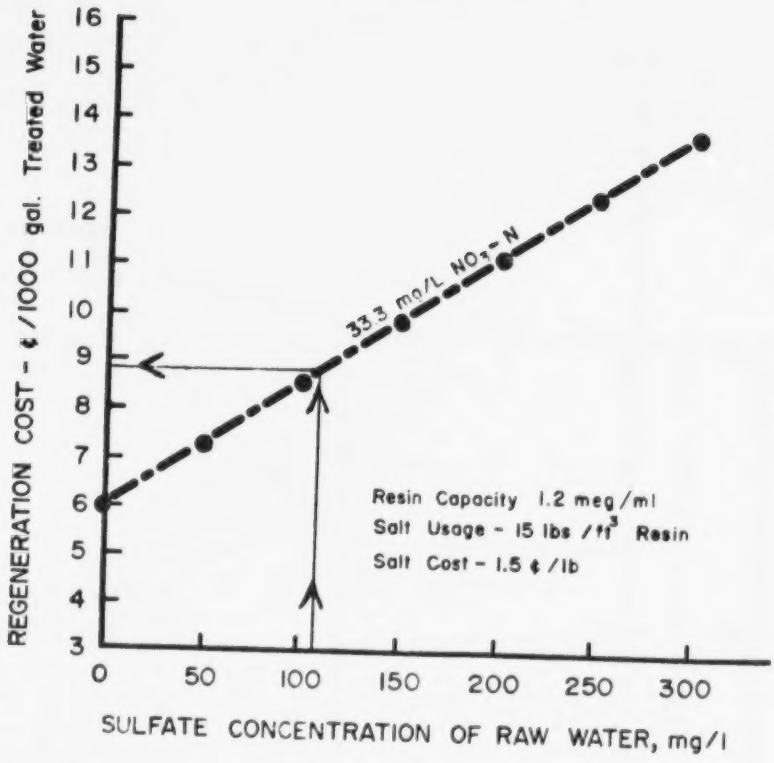


Figure 19. Regeneration Costs vs. SO_4 and NO_3 Concentration(11)

TABLE 16

OPERATION AND MAINTENANCE COST SUMMARY FOR PRESSURE ION EXCHANGE NITRATE REMOVAL[1]

Plant Flow Rate (gpd)	Electrical Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/year)	Labor (hr/yr)	Total Cost* ($/yr)
70,000	13,540	126	13,666	$ 1,890	1,000	$12,300
270,000	21,550	510	22,060	6,340	1,400	21,000
425,000	26,160	790	26,950	9,660	1,550	25,970

* Calculated using $0.03/kw-hr and $10.00/hr of labor.

EXAMPLE OF APPROXIMATING COSTS FOR A 100,000 GPD* NITRATE REMOVAL SYSTEM

STEP 1: Calculate cost adjustment factors as of June 1982

A. Construction Cost Escalation Factor (CCEF) $= \frac{\text{Current ENR CCI}}{\text{Base ENR CCI}}$

The cost curves of Reference 1 are based on October 1978 costs, when the ENR Construction Cost Index (CCI) was 265.38. The June 1982, ENR CCI was 352.92.

Therefore, CCEF $= \frac{352.92}{265.38} = 1.33$

B. Maintenance Material Cost Escalation Factor (MMCEF) $= \frac{\text{Current PPI}}{\text{Base Year PPI}}$

The October 1978 Producer Price Index (PPI), issued by the U.S. Department of Commerce, was 199.7. The June 1982 PPI was 299.4.

Therefore MMCEF $= \frac{299.4}{199.7} = 1.50$

STEP 2: Estimate Construction Cost Using Figure 17

From Figure 17, construction cost in October 1978 dollars is $65,000.

June 1982 Construction Cost = $65,000 x CCEF
= $65,000 x 1.33
= $86,450

STEP 3: Estimate Annual O&M Cost

A. Maintenance Material

From Figure 18, October 1978 annual maintenance material cost is $2,800.

June 1982 Maintenance Cost = $2,800 x MMCEF
= $2,800 x 1.50
= $4,200

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* Note that this is treated flow, before blending. Refer to Section IV for a discussion of total blended flow computations.

EXAMPLE OF APPROXIMATING COSTS
FOR A 100,000 GPD NITRATE REMOVAL SYSTEM
(Continued)

B. Energy Cost

Energy Use = Process Energy + Building Energy*

From Figure 18:

Energy Use = 200 kwh/year (process) +
16,000 kwh/year (building)
= 16,200 kwh/year

$$\text{Energy Cost/Year} = \text{kwh/year} \times \frac{\text{energy cost}}{\text{kwh}}$$

For this example, assume energy cost of $0.05/kwh

Energy cost/year = 16,200 x $0.05
= $810

C. Labor Cost

From Figure 18, labor, hour/year = 1,100 for a 100,000 gpd system. If labor costs $12.00/hour (including fringe costs), annual labor cost is calculated as follows:

Annual Labor Cost = 1,100 hr/yr x $12.00/hr.
= $13,200

D. Regenerant (salt) cost per day (assume sulfate concentration of 100 mg/l and nitrate concentration of 30 mg/l NO_3-N).

From Figure 19, unadjusted cost for 100 mg/l sulfate is 8.6¢/1,000 gal.

If salt costs 3¢/lb:

$$\text{Cost/day} = \frac{8.6¢}{1{,}000 \text{ gal.}} \times 100{,}000 \text{ gpd} \times \frac{30.0}{33.3} \times \frac{3}{1.5}$$

= 1550¢/day or $15.50

Cost/year = $15.50 x 365
= $5,658

* Building energy is very dependent on climate. If possible, estimate this directly for your area.

EXAMPLE OF APPROXIMATING COSTS
FOR A 100,000 GPD NITRATE REMOVAL SYSTEM
(Continued)

STEP 4: Annualize Construction Cost

If the cost of money is 10 percent, and the project has a 20-year financing period, the annualized construction cost is determined as follows:

Annualized Capital Cost = Capital Cost x
Capital Recovery Factor, 10 percent, 20 years

The capital recovery factor from Table 15 for 10 percent and 20 years is 0.117460.

Annual Capital Equivalent = $86,450 x 0.117460
= $10,154/year

STEP 5: Determine Total Annual Costs by Summing the Annual Costs of Construction with O&M and Determine Cost per 1,000 Gallons Treated

A. Annual Cost Summary

Capital	$10,154
O&M	
Maintenance Material	$ 4,200
Energy	$ 810
Labor	$13,200
Regenerant	$ 5,658
TOTAL	$34,022

B. Annual Treated Flow, Thousands of Gallons

$$\text{Annual Treated Flow (1,000 gal)} = 100{,}000 \text{ gal/day} \times \frac{1}{1000} \times 365$$
$$= 36{,}500$$

C. Cost per 1000 gallons treated

$$\text{Cost/1000 gal} = \frac{\text{Annual Cost}}{\text{Annual Treated Flow (1000 gal)}}$$

$$= \frac{\$34{,}022}{36{,}500} \text{ thousand gal/year}$$

Cost/1000 gal = $0.93

EXAMPLE OF APPROXIMATING COSTS
FOR A 100,000 GPD NITRATE REMOVAL SYSTEM
(Continued)

NOTE THAT THIS IS THE UNBLENDED TREATMENT COST. IN MOST CASES, ONLY A PORTION OF THE FLOW WILL BE TREATED. THE COST PER THOUSAND GALLONS OF <u>TOTAL</u> FLOW WOULD THEREFORE BE LESS. FOR EXAMPLE:

If the water in this example has a NO_3-N of 30 mg/l and the system will remove all but 0.5 mg/l of the nitrate from the <u>treated</u> flow, the potential total system flow, after blending, and the cost per 1000 gallons of total (treated + blended) flow can be determined using the following formulas.

$$Q\ Total = \frac{Q\ Treated}{1 - \frac{(Final\ NO_3\text{-}N - Treated\ NO_3\text{-}N)}{(Untreated\ NO_3\text{-}N - Treated\ NO_3\text{-}N)}}$$

For a final blended water of 9 mg/l NO_3-N:

$$Q\ Total = \frac{100,000}{1 - \frac{(9.0 - 0.5)}{(30.0 - 0.5)}}$$

$$= \frac{100,000}{0.712}$$

$$Q\ Total = 140,450\ gpd$$

Cost per thousand gallons of <u>total</u> flow then becomes:

$$\frac{Cost/1000\ gal}{(Total\ Flow)} = \frac{Cost/1000\ gal}{(Treated\ Flow)} \times \frac{Q\ Treated}{Q\ Total}$$

$$= \$0.93 \times \frac{100,000}{140,450}$$

$$\frac{Cost/1000\ gal}{(Total\ Flow)} = \underline{\$0.66}$$

FUNDING SOURCES

The principal financing options available to small water systems for treatment process improvement can be categorized as follows:

- o Self financing
  - User charges and fees
  - Bonding/loans
- o Direct grant programs
- o Subsidized/assisted loan programs
- o Other assistance programs
  - Labor sharing with other systems
  - EPA technical assistance activities

These are discussed in turn below.

Self Financing

Water utilities process, deliver and charge consumers for potable water. In this, they bear close resemblance to other businesses that also produce and sell a product. Most of these utilities, publicly or privately owned, do not normally have problems financing needed capital improvements either through user fees or changes in the water rate, or by bonding.(16) However, the financing needs for constructing and operating nitrate removal systems may strain the resources of small community water systems, either by requiring capital expenditures beyond their ability to finance, or by causing large incremental increases in user charges. The latter course may incur substantial consumer resistance to the improvement program, a major impediment in the case of publicly owned systems. Very small systems may be particularly vulnerable to problems in this regard

The prime considerations for self-financing include the following:(16)

- o Amount of revenues available for payment of interest costs
- o Ratio of new treatment capital costs to existing assets
- o Percent rate increase needed to finance and operate treatment
- o Ratio of the typical residential water bill to the community's median family income

In competing for funds on the private capital markets, the larger utility is expected to have a debt service ratio (ratio of income after operating expense to interest costs) of 1.3 and income at least twice that of interest charges. Private utilities must be showing a net profit, after taxes, of 10 to 13 percent. User bills should run less than 1.5 to 2.0 percent of median family income.(16)

Smaller utilities may be substantially less robust financially, and still be able to raise money locally. Utility customers may be willing and able to put up the needed capital. Even so, the utility should have a debt service ratio of at least 1.0 so interest and bond repayment schedules can be met.

Grant Programs

The principal financial assistance program available to small community water systems (public or private nonprofit) is operated by the Farmers Home Administration (FmHA) of the Department of Agriculture. FmHA can grant up to 75 percent of the cost for installation, repair or upgrading community water systems that serve fewer than 10,000 people with emphasis on farmers and other rural residents.

Program aid priorities are established considering the following criteria:

- Public bodies and towns with emphasis to those serving 5,500 people or less
- Systems that will achieve compliance with Safe Drinking Water Act as a result of the improvements
- Low income communities
- Systems proposing to merge and/or regionalize
- State recommended projects
- Projects promoting water energy conservation

FmHA can be contacted for further information at any one of 340 offices nationwide.

The Department of Housing and Urban Development (DHUD) has a program of Community Development Block Grants (CDBG), funds from which local water treatment projects can be funded. The CDBG program combines a wide range of public construction and allocation of funds is normally carried out by local committees, with Federal oversight. The program is usually operated at the county or city level and these sources can provide the information needed to apply for funds.

Direct Loan Programs

Two federal agencies currently operate direct loan programs:

- Department of Interior - has two programs available to public nonfederal entities in the 17 western states.
- Farmers Home Adminstration - has loan program with similar criteria to those used in their grant program. The loan can be for 100 percent of the project cost.

Loan Guarantee Programs

The Farmers Home Administration has a Business and Industry Loan program available to public or private organizations, particularly those located in rural areas and serving fewer than 50,000 persons. Loan guarantees range up to 90 percent of face value.

Other Forms of Assistance

Other ways of reducing financing and/or operating costs include the following:

- Bond banks - Several states have central bond banks that assist localities in the mechanics of bond financing. By aggregating small bonds into larger ones, interest costs may be reduced and bond placement enhanced.

- Research and development - The U.S. Environmetal Protection Agency (EPA) has funded a few pilot and demonstration projects for water and wastewater systems using uncommon technology. Pilot studies at McFarland, California, were carried out as part of an EPA research project.

- State loan programs - Several states provide direct loans for construction of public water and sewer projects. The programs are normally operated under the aegis of state economic development offices.

- Shared operator costs with other nearby utility(s) - Ion exchange nitrate removal does not require full time supervision; hence, operator costs could be divided between two or more utilities where travel distance permits. Regionalization is one approach to shared operating expenses.

VI. OPERATION AND MAINTENANCE

Nitrate removal using salt regenerated strong base ion exchange will provide long service, with low maintenance providing that precautions are taken to prevent excess raw water turbidity or fouling of the resin. The equipment is widely used for water softening and industrial water treatment and does not require continuous operational supervision. Preventive maintenance (PM) is the key to long trouble-free performance. This section sets out recommended monitoring and PM activities for a typical small nitrate removal system.

OPERATOR REQUIREMENTS

Operation of an ion exchange system does not require specialized operator skills. The operator should be reasonably proficient in plumbing and electrical skills and should understand the operation and repair of simple pumps, valves, water meters and electrical controls. He or she must be capable of carrying out a program of periodic sampling and be able to use a packaged test kit, make simple calculations and record results. The operator should be of sufficient intelligence and schooling so that he or she can be trained in the fundamentals of process operation and be able to fully grasp the importance of avoiding nitrate breakthrough.

Operator time requirements are dependent on system size. However, it is not likely that the operator will spend more than several hours per day carrying out the monitoring and PM activities described herein.

MANUALS, EQUIPMENT AND SUPPLIES NEEDED

Provide the system operator with the guide manuals, tools, analytical equipment and supplies needed to properly maintain the system. For example:

- o System operation and maintenance manual for each individual piece of equipment and the system as a whole which describes:
  - Startup and test procedures, routine (preventative) maintenance procedures, and troubleshooting guide.
  - Schedule of routine maintenance activities and tools/supplies for each task. Schedule should include daily, weekly, monthly, quarterly and annual activities as needed.
  - Sources, including name, address and telephone numbers, for emergency parts and service. This should also be posted near the equipment.
  - Operational directions, including detailed control settings for electrical controls, motorized valves, flowmeters, pumps, etc.
  - Sampling and test procedures and schedules for process monitoring

and reporting to the state.

- Appropriate forms for recording maintenance and water quality data. Format of recommended record keeping.

o Recommended tools and critical spare parts for each item, such as lubricants, valve and pump gaskets and packing, electrical fuses. Stock key spare parts that are not available locally or overnight from manufacturer's warehouse.

o Field test kits for process control:

- turbidity
- nitrate
- chlorides
- sulfates (if high or variable)

o Sample bottles, mailing packages and complete mailing instructions including name, address, telephone number of state approved laboratory.

o Supply of regenerant chemicals (e.g., salt).

MONITORING

Monitoring encompasses two activities:

1. Monitoring to satisfy Federal or State requirements under the National Interim Primary Drinking Water Requirements (NIPDWR) of the Safe Drinking Water Act (SDWA)

2. Monitoring for process control

Monitoring/Reporting requirements for nitrates under the Safe Drinking Water Act are quite minimal. Community water systems using surface water must report the result of nitrate analyses to the State or EPA every year; those using ground water must report nitrates to EPA only once every 3 years unless otherwise specified. For non-community systems state health departments may require more frequent reporting. Illinois, where nitrate pollution of ground and surface water occurs as a result of heavy agricultrual activity, requires monthly reporting of nitrates. Note that test kit data do not satisfy this requirement. You must have these analyses performed by a state approved laboratory. When drawing a sample for certified analysis, you should simultaneously check nitrate levels with your field test kit. This will give a laboratory check against test kit results. Table 17 illustrates a sample form that could be used to record test kit and laboratory analyses. A permanent record and file for both test kit data and laboratory analysis reports should be maintained.

Approved monitoring for process control can be carried out using a calibrated field test kit (Table 3). A sample schedule of monitoring activities is given below. Table 17 is a sample data sheet that might be used to record these data.

Daily

o Use nitrate test kit to check

- Raw water nitrates

TABLE 17

SAMPLE MONTHLY DATA SHEET

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
DAY	FLOW METER READINGS					NO_3-N IN SERVICE				REGENERATION CYCLE CHECK					
	Treated Water	Previous Day	Blend Water	Previous Day	Total Water	Raw NO_3-N	Exchanger Out NO_3-N	Blend NO_3-N	Chlorides Out	Check Date / Time	NO_3-N Out	Chlorides Out	Waste Flow Meter Readings		Salt Added Lbs
													Start	Finish	

MONTHLY LAB DATA

ROUTINE		CHECK		OTHER ANALYSES		
NO_3-N Reading	Date	NO_3-N Reading	Date	Item	Reading	Date
			Chlorides			
			SO_4			

CALCULATIONS

Treated Flow = column 2 − column 3

Blended Flow = column 4 − column 5

Total Flow = Treated Flow + Blended Flow

Wastewater Flow = column 15 − column 14

- Exchanger product water nitrate
- Blended water nitrate*

o Use chloride test kit to check

- Raw water chlorides
- Exchanger product water chlorides

o Use turbidity test kit to check

- Exchanger feed water turbidity
- Product water turbidity

o Check and record treated flow, blended flow, waste flow and total flow.

Regeneration Cycle Check**

o Verify operation of full cycle of back wash

- Time each phase of cycle and compare to set times on time clock.

- Verify brine flow during brine cycle. Visually check that brine level lowers in salt tank when back wash valve is in brine position.

- Check flow meter on waste line to verify water flow for each cycle and visually observe flow at waste line.

* Continuous nitrate monitoring may be required by the State.

**Check frequency determined by manufacturer's recommendation and back wash cycle frequency.

o Use test kits to check.

- Nitrate and chloride levels in feed and product water after unit returns to normal operation.

PREVENTIVE MAINTENANCE

Preventive maintenance (PM) is the key to reliable service and long equipment life. Close attention to PM activities will reduce annual costs and minimize system failure. Summarized below are typical PM activites for a nitrate removal system. A schedule of PM tasks should be included in the plant O&M manual. Table 18 is a PM equipment check list that could be applied to a small system such as the one at Curryville, Pennsylvania (also see Section VII).

Typical Daily PM Checks

o Pumps (if any):

- Overheating. The pump motor should not smell hot nor burn the hand when touched.

- Noisiness/vibration. Rattling and grinding noises may indicate serious bearing problems and/or shaft misalignment.

- Water leaks from packing glands and fittings.

- Loose hardware, mountings, electrical connections.

- Surface rusting/corrosion.

- Motor ventilation ports. Ports should be clear and free of dirt, oil and moisture.

TABLE 18
SAMPLE PERIODIC EQUIPMENT CHECK LIST FOR A SMALL ION EXCHANGE UNIT

I. In Service Operation

1. Brine Tank

Float valve	/ / OK / / Leaking / / Other
Salt level	/ / OK / / add salt _____ (Amount)
Sump/draw line	/ / OK / / needs cleaning
Container	/ / OK / / not OK _____ (describe)

2. Motorized valve

Leaking	/ / NO / / Yes _____ (where)
Noisy	/ / NO / / Yes
Oil level	/ / OK / / Oil added _____ (amount)
In correct position	/ / NO / / Yes _____ (position)
Water leak at waste line	/ / NO / / Yes _____ (amount)

3. Flow totalizer

Sensor leaking	/ / NO / / Yes
Check against main flow meter	/ / OK / / Reading high / / OK / / Reading low
Unusual noises	/ / NO / / Yes

II. Regeneration Cycle Check

1. Brine Tank

o Does brine level lower at a rate which corresponds to the rate required for regeneration when motorized valve in "brine" position?

/ / Yes / / NO--Inches/minute _____
If no - check:

Supply pressure _____
Waste line clear _____
Brine suction line clear _____
Valve malfunction _____
Air leak in brine suction line _____

- Check brine flow rate during brine cycle.

	Start	Finish
Inline meter reading (gallons)	_____	_____

Flow rate = $\frac{\text{(finish) - (start)}}{\text{12 minutes}}$ = ___ _____ gpm

NOTE: Correct flow rate is 11 gpm (for Permutit ED-20 System).

2. Motorized valve

- Elapsed Time

	Actual (Minutes)	Correct (Minutes)
Backwash	_____	_____
Brine draw	_____	_____
Slow rinse	_____	_____
Fast rinse	_____	_____

- Observe operation

	Yes	No
Oil leaking	_____	_____
Water leaking	_____	_____
Noisy	_____	_____
Correct position for each cycle	_____	_____

3. Waste flows

- Observe free flow at waste line for each part of regeneration cycle

_____

4. Flow totalizer

Inline meter readings:

Regeneration:

Start of cycle	_____	(gallons)
End of cycle	_____	(gallons)
Difference	_____	(gallons)

NOTE: Should be about 670 gallons (for Permutit ED-20 System).

In Service Cycle

Start of cycle _____ (gallons)
(End of last regeneration cycle)

End of cycle _____ (gallons)
(Beginning of regeneration cycle)

Difference _____ (gallons)

Totalizer Trip Setting _____ (gallons)

NOTE: These should be approximately equal. If more than 10 percent difference, check both flow meters per manufacturer's recommendations.

- o Motorized flow valves:
  - Water, oil leaks.
  - Rough operation, noisiness during regeneration cycle.
  - Leaks from waste line when valve is in the "off" or "in service" position.
  - Proper valve positioning.
- o Flow meter/flow totalizers:
  - Comparison of main flow meter and check flow meter for equivalent recordings.
  - Leaking, moisture under meter glass, sticking of meter in operation.
- o Blending flow valve/flow meters:
  - Check daily for correct flow splitting
- o Brine/salt storage:
  - Salt level in brine tank.
  - Stored salt quantity.
- o Tanks, pipes and appurtenances:
  - Leaks, cracks, corrosion.

Checks During Regeneration

- o Check time clock and relays for:

  Noisiness
  Sticking
  Overheating or hot smell
  Time accuracy

- o Check automatic valve for:

  Leaking
  Sticking
  Complete cycling

- o Check brine system for:

  Flow meter operation
  Adequate salt in brine tanks

- o Waste flow:

  Free flowing
  Evidence of resin in waste flow

Other Periodic Activities

- o Pumps/motors:

  Lubricate in accordance with manufacturer's recommendation

- o Flow meters:

  Calibrate in accordance with manufacturer's recommendation

- o Time clock/relays/automatic valve
  - Lubricate, adjust in accordance with manufacturer's recommendation

EMERGENCY PROCEDURES

Salt regenerated ion exchangers do not use or give off dangerous chemicals or fumes. The principal hazard to operators associated with their use is the result of skin or eye contact.

Operation beyond nitrate breakthrough, however, will result in elevated product water nitrate levels. After resin

exhaustion, the influent sulfates will replace nitrates in the bed. As a result, the product water will have MORE nitrate than the raw water. This could be highly dangerous to the consumers.

Should this situation occur:

SHUT THE SYSTEM DOWN IMMEDIATELY. Check stored water for high nitrates. If high, notify the public and state representatives immediately. Prevent stored water from being distributed if possible, recognizing the potential hazards associated with insufficient capacity in case of fire. Regenerate exchanger immediately, checking each step in the regeneration process. When water processing resumes, check for correct effluent nitrate levels. Flush the system with the properly treated water and ensure high nitrate levels are eliminated in all parts of the system. Review and change regeneration program as needed to avoid a recurrence.

SAFETY PROCEDURES

There are no substantial hazards associated with the operation or repair of salt regenerated systems. Manufacturer's recommended practices should be clearly posted on site and followed. No special safety equipment is required. Waterproof gloves may be worn when working with the brine system to avoid skin irritation.

RECORD KEEPING

Records of <u>all</u> process monitoring and PM activities in addition to the records required by state and federal regulations should be organized and retained. Complete, well organized records create a historical basis over time that will provide great assistance in understanding and dealing with equipment problems and raw water quality variations. Keep records in a central file, convenient to plant operators, and protected from extremes of heat, cold or moisture. Periodically update and cull obsolete files.

VII. CASE HISTORIES

Use of strong base resins in ion exchangers for deionization, including nitrate removal, is widely practiced in industrial waste treatment. Experience in potable water service for removing nitrate from drinking water supplies, however, is limited. The following two localities have accrued some experience with the process, using equipment typical for smaller systems.

Locality	System
Curryville, Pennsylvania	3000 gpd fixed bed salt regenerated anion exchange unit (40,000 gpd available capacity)
McFarland Mutual Water Co. McFarland, California[17]	Pilot study for 1.0 mgd fixed bed system

CURRYVILLE, PENNSYLVANIA

Curryville provides an example of a very small system treating a water which only slightly exceeds the standards. Nitrate nitrogen is only about 11 mg/l NO_3-N. The utility's total daily flow is less than 45,000 gallons per day of which about 10 percent is treated for nitrate removal, then blended with the main flow to reduce nitrates to 9 mg/l (NO_3-N).*

The ion exchanger, a single fixed bed Permutit water softener style unit (Model ED20) was installed in early 1979 at a cost of $30,000.

Figure 20 shows the equipment house, which houses a small gas chlorinator and the ion exchange unit. Figure 21 is a photograph of the ion exchange unit inside the house. The brine tank is in the foreground, nearest the door. The main flow control valve, an electrically driven flow valve, is located atop the ion exchanger in the rear of the room. It is controlled by a totalizing flow controller, located to the right of the unit.

Table 19 provides pertinent design parameters for this unit. As presently operated, the unit regenerates automatically after 18,000 gallons of water has been treated, using about 45 pounds of salt. The regeneration cycle lasts about 70 minutes and consumes 130 gallons of brine which is wasted to a septic tank adjoining the treatment house. (This procedure is not encouraged as it may lead to ground water pollution.)

The plant operator, employed on a part time basis, visits the treatment plant twice weekly,

* No sulfate data available.

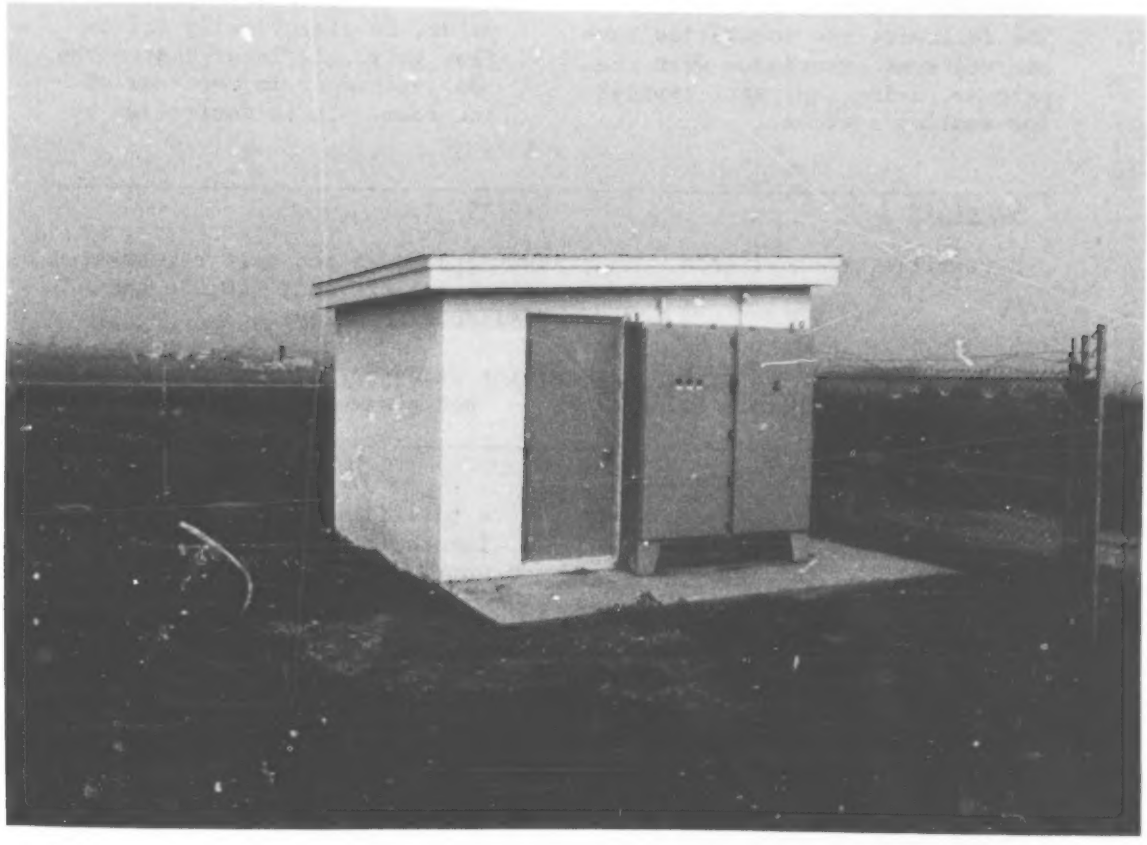

Figure 20. Curryville, Pennsylvania, Equipment Housing

Figure 21. Curryville, Pennsylvania, Nitrate Removal System

TABLE 19

DESIGN AND OPERATING DATA FOR THE CURRYVILLE, PA NITRATE REMOVAL SYSTEM

Type exchange unit	Single bed anion exchanger
Manufacturer/Model:	Permutit, Model ED20
Costs (1979 Dollars):	
Installed Cost	$30,000 (approximate)
Housing	$39,100 for building, fencing and hook up to adjacent well
Engineering	$10,000
Resin Manufacturer/Type:	Ionac, A550 Strongly Basic
Bed Dimensions:	
Diameter	20 inches
Height	32 inches
Volume	5.5 cu.ft.
Flow Through Exchanger:	
Design - average	28 gpm
- peak	36 gpm
Actual	0.45 gpm*
Average Daily flow treated (gal)	
Regeneration Cycle:	
Time	70 minutes
Salt Consumption	45 pounds
Pounds Salt/cu.ft. resin	8.2 pounds/cu.ft.
Water Consumption	
backwash	200 gallons
brine	130 gallons
slow rinse	190 gallons
fast rinse	150 gallons
Total	670 gallons

* Flow rate on 24-hour/day basis. In practice, unit is operated 6 hours/day or less.

spending less than one hour per visit. The following checks and maintenance operations are routinely carried out:

1. Salt level in brine tank is checked
2. Gear box oil on motorized valve is checked
3. Setting on flow splitter valve checked to verify that 10 percent of flow is being treated
4. Operation of flow recorder/ controller is checked

The operator does not routinely check the operation of the regeneration cycle, due to its infrequency. Nitrate samples are drawn quarterly at a cost of $50 per sample analysis. The utility does not presently have a field kit for nitrate analysis, but plans to purchase one in the near future. The operator reported that the unit has been trouble free after some startup problems were remedied. No operating cost data were available at the time of the site visit.

MCFARLAND MUTUAL WATER COMPANY

In cooperation with the U.S. EPA's Drinking Water Research Division, Cincinnati, Municipal Environmental Research Laboratory (MERL), Boyle Engineering Corporation has carried on extensive pilot studies at the McFarland Mutual Water Company.[17] This work, developing an optimized ion exchange nitrate removal system for a high sulfate well water, has resulted in several discoveries that may be of significance in designing new systems.

- Nitrate at McFarland was readily removed from even high sulfate waters at flow loading rates greatly in excess of those normally recommended by equipment and resin suppliers.
- High loading rates, coupled with use of readily available and adaptable equipment, substantially reduces expected capital cost for a 1.0 MGD system.
- Packaged test kits, such as manufactured by the vendors shown in Table 3, while not accurate enough for testing for compliance with standards can be calibrated and used effectively for pilot work and process control.

McFarland's water supply is drawn from several wells. The test well that is not presently used for water supply contains over 20 mg/l of nitrate nitrogen and over 300 mg/l of sulfate (as SO_4). Because of its very high sulfate concentration, the water would seemingly be quite difficult and costly to treat using ion exchange. Results of the pilot study, however, show that the water can be treated economically, largely due to the discovery that high flow rate, partial regeneration and equipment and resins that are commercially available can be used successfully.

Column Tests

Column tests, using resin manufacturer's recommendations, were conducted for the 4 resins tested at McFarland. The columns,

TABLE 20

PILOT COLUMN DATA

Item	Data
Column Size	2 inches inside diameter 4 feet high 3.14 square inches cross sectional area
Bed Depth	24 inches
Bed Volume	0.044 cubic feet
Test Flow Rate	2.5 to 11.2 gpm/cu.ft. of resin
Regenerant Flow Rate	1.315 gallons/hour, 90 minutes contact time
Regenerant Composition	6 percent salt (NaCl) solution

2 inches in diameter and over 4 feet tall, were constructed and operated as described in Table 20.

All of the resins tested were of the strong base type. However, they varied as to their specific resin type. Selectivity and porosity seems to have been inconsistent (resistance to water flow through bed).

Pilot Scale Unit

Based on results from column testing, a pilot scale unit was adapted from commercially available equipment manufactured by the Culligan Company. The unit, shown schematically in Figure 22, is designed to handle relatively high flow rates using a coarser, semiporous resin. Several modifications were made to the unit to render it suitable for the test, including improving the inlet configuration and brine consumption monitor. At the high backwash/regeneration flows used, it was also found desirable to screen the inlet/backwash exit manifold to prevent resin washout.

Results from the high flow rate loading of this unit demonstrated that flows of 6 gpm per cubic foot of resin are feasible with this feed water. Other tests indicated that varying regeneration conditions result in similar system performance over a wide range of regenerant consumption, suggesting that operating costs could be substantially reduced with little loss of efficiency by optimizing regeneration parameters.

Proposed Design of 500,000 gpd Full Scale System

Based on the pilot study, a full scale system design was developed and costs were esti-

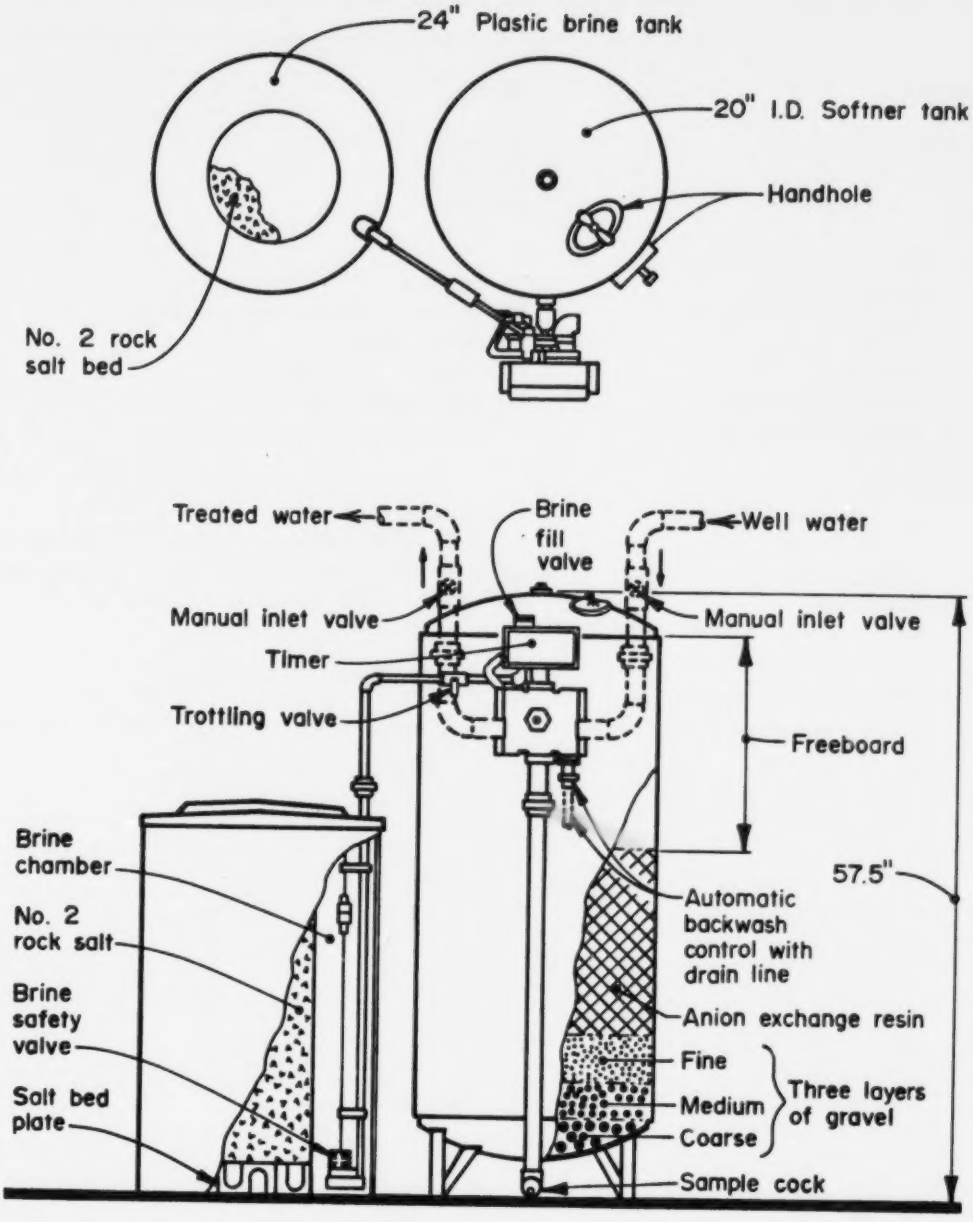

Figure 22. Pilot Scale Test Unit Used at McFarland

TABLE 21

MCFARLAND, CALIFORNIA 0.5 MGD SYSTEM DESIGN PARAMETERS

Parameter	Data
Flow Rate - average	0.5 mgd 347 gpm
maximum	454 gpm
Resin Bed:	
- depth	36 inches
- diameter	72 inches (each, two tanks)
- volume	85 cubic feet
- loading	6.67 gpm/cubic foot
- surface flow	20 gpm/square foot
- capacity/cycle	126,500 gallons
Regeneration:	
- brine concentration	6 percent
- brine flow	63 gpm, 846 gallons total, 15 minutes
- rinse flow	49 gpm, 2225 gallons total, 45 minutes
- backwash	140 gpm, 1400 gallons total, 10 minutes
- total water flow per cycle (backwash recycled)	3071 gallons

TABLE 22

MCFARLAND, CALIFORNIA COST ESTIMATE FOR 0.5 MGD SYSTEM (1980)*

Number	Description	Cost
2	Fabricated resin tanks 72" x 60" (including valves, electrical controls, and flow distributors)	$33,117
2	Alternators	640
2	4-inch reset meters	4,893
4	Solenoid kits	122
1	Brine pump	416
1	40-Ton brine maker 10' X 14'6" (including level controls, sight glasses)	15,430
170	Cubic feet resin @ $150/cu.ft.	25,500
	Plumbing installation	2,000
	Concrete pad	2,000
	Startup and loading by vendor	1,000
	TOTAL	$86,818

* Does not include engineering, contingencies and housing. Based on direct quotations from supplier for commercially available equipment.

mated. Table 21 provides the design parameters for the 500,000 gpd* system. Cost estimates are given in Table 22, and provide estimated installed cost less engineering and contingencies. Even if these items cost 30 percent of the capital cost, the total cost would be less than $113,000 (1980 dollars). The cost of the McFarland system could be much higher if equipment housing is included.

Operating costs were not directly estimated in the report. However, regenerant costs for the optimized regenerating system apparently would range from 4 to 6 cents per 1000 gallons, based on the data presented.

The McFarland costs assume use of commerically available equipment with minimal installation difficulties. Housing is not included. Costs were estimated in late 1980 based on direct quotations from suppliers and installers. No allowance has been made for contingencies or engineering costs.

* Treated flow.

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APPENDIX A

Abbreviations

BV	bed volume (of resin in ion exchange)
cu. ft.	cubic foot (volume)
sq. ft.	square foot (area)
gr.	grain (unit of mass)
gpm	gallons per minute (flow)
gpw	gallons per week
GPM	gallons per minute based on daily total flow
GPMc	gallons per minute based on weekly total flow
JTU	Jackson Turbidity Unit
mg/l	milligrams per liter (metric)
mgd	million gallons per day
Q	flow rate, in units indicated
gpm_u	unit flow rate

Conversion Tables

VOLUME

	Cubic Feet	Gallons (U.S.)	Liters
1 cu. ft.	1	7.48	28.3
1 gallon (U.S.)	0.134	1	3.785
1 liter	0.353	0.264	1

MASS

	Pounds	Grams	Grains	Kilograms
1 pound	1	453.6	7,000	7
1 gram	0.0022	1	15.43	0.01543
1 grain	0.000143	0.065	1	0.001
1 kilograin	0.143	65	1,000	1

CONCENTRATION

	Gr./gallon	Gr./cu.ft.	Lb./gallon	mg/l
1 gr./gal.	1	7.48	0.143	17.17
1 gr./cu.ft.	0.134	1	0.019	2.30
1 lb./gal.	7	0.936	1	119.841
1 mg/l	0.058	0.436	0.0000083	1

APPENDIX B

The general equation that is used to determine the common basis quantity of a substance in term of milliequivalents is given below:

$$\frac{\text{Milliequivalents (meq)}}{\text{liter (l)}} = \frac{\text{Conc of Substance mg/l}}{\text{Equivalent Weight of Substance in Milligrams per Millequivalent } (\frac{mg}{meq})}$$

If you know any two of these values in the general equation, you can determine the value of the third. For this example, the equivalent weight is known, the concentration is known and by simple division, the number of milliquivalents/liter can be calculated:

Given the following analysis:

1. Express the NO_3-N (nitrate as nitrogen) concentration of 15 mg/l as NO_3-NO_3 from Table 10, and milliequivalents of nitrate per liter.

   Using the general equation:

   $$(meg/l) = \frac{\text{Conc of Substance (mg/l)}}{\text{Equivalent Weight of Substance (mg/meq)}}$$

   Substitute the known values and solve for the unknown value:

   $$\frac{\text{meq nitrogen}}{1} = \frac{15 \text{ mg/l } (NO_3\text{-}N)}{14.007 \text{ mg/meq}} = 1.07$$

2. Express the milliequivalents of nitrogen as concentration of nitrate:

   $$meq/l = \frac{\text{Conc of Substance}}{\text{Equivalent Weight of Substance}}$$

   Therefore:

   Conc of nitrate = meq/l x milliequivalent weight of substance
   Conc of nitrate = 1.07 meq/l x 62.005 mg/meq
   = 66.3 mg/l NO_3

From the example it can be seen that if it is desired to express the concentration of one constituent (such as nitrogen) in terms of another constituent (such as nitrate) two steps are involved:

1. Converting the original concentrations to the common base milliequivalents/liter, and

2. Changing the common base to a concentration of the new constituent.

This process can be simplified by writing one general equation that combines both steps. The general equation is:

$$Conc_B = Conc_A \times \frac{\text{Milliequivalent Weight B}}{\text{Milliequivalent Weight A}}$$

Therfore, to convert a concentration of 15 mg/l nitrate which is reported as nitrogen to the equivalent concentration of nitrate as nitrate, substitute the known values into the general equation above as follows:

$$Conc_B\ (NO_3^-) = Conc_A\ (\text{Conc as N}) \times \frac{\text{Milliequivalent Weight B } (NO_3)}{\text{Milliequivalent Weight A (N)}}$$

$$\text{Conc } NO_3^- = 15 \text{ mg/l } \frac{(62.005)}{(14.007)} = 66.4 \text{ mg/l}$$

Grains/gallon, a unit often used in ion exchange practice, is converted to the meq/ml as follows:

$$\frac{\text{gr (as } CaCO_3)}{\text{gal}} \times \frac{65 \text{ mg}}{\text{gr}} \times \frac{1 \text{ meq}}{50.045 \text{ mg } CaCO_3} \times \frac{\text{gal}}{3.78 \text{ l}} \times \frac{1 \text{ l}}{1000 \text{ ml}} = \frac{\text{meq}}{\text{ml}}$$

solving

$$\frac{\frac{\text{gr}}{\text{gal}}\ (\text{as } CaCO_3)}{2910} = \frac{\text{meg}}{\text{ml}}$$